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HUMAN-CENTERED TECHNOLOGIES AND PROCEDURES FOR FUTURE AIR TRAFFIC MANAGEMENT

1996 ACTIVITIES REPORT, CONTRACT NO. NAG2-995

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January 31, 1997

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Columbus, Ohio 43210

To Judy ManGau
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This is a report of research activities conducted during 1996 under the provisions of contract NAG 2-995 between the National Aeronautics and Space Administration-Ames Research Center, The Ohio State University, Ohio University, and the University of Illinois. The technical monitor was Dr. Judith Orasanu. The conclusions incorporated in this series of reports are those of the authors and do not represent the views of NASA or any other government agency.

This volume incorporates several technical reports prepared by various members of the research team. The reports submitted here include:

1. Executive Summary and Recommendations
2. Methods for the Development of Future System Requirements: The Envisioned World Problem, the Future Incident Technique and Conceptual Walkthroughs
3. Human Factors Issues in the Design of a More Flexible ATM Environment: Knowledge Elicitation Based on the Expanded National Route Program
4. Human Factors Issues in the Design of a Future Free Flight Environment: Dealing with a Mixed Locus of Control
5. Human Factors Issues in the Design of a More Flexible ATM Environment: Cognitive Demands of Management by Exception
6. Factors Influencing Controller Performance: Implications for a Free Flight Environment
7. Human Factors Issues in Communication and Coordination: Practice-Centered Procedures and Technologies in Support of Effective Air-Ground Coordination in Future ATM Operations
8. Advanced Air Transportation Technologies: Problem Definition and Exploration of a Solution Space

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HUMAN-CENTERED TECHNOLOGIES AND PROCEDURES FOR FUTURE AIR TRAFFIC MANAGEMENT

1. EXECUTIVE SUMMARY AND CONCLUSIONS

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Introduction

In this project, we have been exploring the use of various methodologies to predict the impact of future Air Traffic Management (ATM) concepts and technologies. In applying these methodologies, our emphasis has been on the importance of modeling coordination and cooperation among the multiple agents within this system, and on understanding how the interactions among these agents will be influenced as new roles, responsibilities, procedures and technologies are introduced. To accomplish this, we have been collecting data on performance under the current air traffic management system, identifying critical problem areas and looking for exemplars suggestive of general approaches for solving such problems. Using the results of these field studies, we have developed a set of concrete scenarios centered around future system designs, and have studied performance in these scenarios with a set of 40 controllers, dispatchers, pilots and traffic managers.

In a preliminary report submitted on 19 July 1996 (Smith, Woods et al., 1996), we provided NASA with a compendium of the major recommendations that had resulted from our research under the AATT Program to that date. Recommendations 1-3 dealt with general approaches that our findings suggested should be incorporated in future AATT Program activities, while Recommendations 4-11 identified some specific topics and technologies that merit research and development activities. Those recommendations are repeated here.

This summary is organized as follows. Section 1 describes the general design philosophy that is supported by our empirical studies. Section 2 briefly summarizes the research methods we have used to identify requirements for future system designs and to evaluate alternative design solutions. These methods are discussed in detail in report no. 2 in this volume. Section 3, and reports 3-7 in this volume, discuss results from several investigations that we have conducted using these research methods. Section 4 provides an overall summary of the section.

1.1 Proposed Design Philosophy

Our central conclusion is that attempts to improve the safety and efficiency of the air transportation system must take a human-centered approach to support the cooperative problem-solving of both airborne and ground-based operators. The impact of new ATM concepts and technologies must be considered in the context of the roles, responsibilities and interactions of the people using them, in terms of procedures and the regulatory environment, in terms of organizational behavior, and in terms of the different types of situations or scenarios that arise in such a system.

In particular, design efforts must explicitly take into consideration the *distributed nature of this system*, which includes human and computerized agents with multiple complementary and competing goals and overlapping responsibilities, who at times have different sources of information and differing situation assessments. Furthermore, we must study how this system, with all of its complex interactions, can evolve from its current state. We need to start with an understanding of interactions within the current system, and then take a hard-headed approach, asking where the real problems lie, and determining where opportunities for improvement with significant payoffs really exist.

Thus, our focus has been on how the participants within the ATM system can coordinate their activities to achieve overall safety and economic goals. We believe this is the appropriate project focus because a fully autonomous air traffic management system, whether air- or ground-based, is not likely to be technically possible or desirable in the foreseeable future given the dynamic and uncertain nature of the national airspace system.

We believe that the allocation of resources for future system development should be based on a broad systems perspective, with emphasis on how system elements interact and how they are to be integrated. One set of methods that can help to accomplish this goal is to construct and use concrete scenarios that focus attention on the necessary interactions among participating agents in proposed ATM systems. Such scenarios can also focus attention on requirements for new technologies in a future system.

We believe that it is important to use empirical methods to provide a basis for developing informed judgments about alternative system enhancements and that such work should take place early in the design process. This requires examining the implications of alternative design proposals in rich, realistic contexts, using experienced practitioners to generate predictions about performance in such future designs. To be cost-effective, the design process also needs to include methods that allow exploration at different levels of fidelity.

1.2 Methods for the Development of Future System Requirements

1.2.1 Introduction

One important question in the development of a future ATM system is methodological: How can we identify system requirements for new ATM concepts and technologies, recognizing the potential for these changes to create new roles and procedures for individual participants, new forms of coordination across personnel and organizations, and new types of information to communicate, assess and integrate? This is difficult in part because the system of interest does not yet exist. A further challenge arises because many details of this future system design are underspecified. To design and test these new roles before committing large pools of resources, we need a method to quickly prototype and study how the people and technologies will coordinate in realistic operational scenarios for different ATM concepts.

Different developers, stakeholders and decision makers are each likely to develop their own insights and views on how the whole system will work in the future. Consequently, another challenge is how to rigorously explore the many implications of these different viewpoints. For without doing so, it would be easy to oversimplify the impact of a new system on the roles, decisions, coordination needs, and information requirements of the people involved in the ATM system.

These characteristics—a still underspecified system design, accompanied by the potential to oversimplify the impact of design decisions on people's roles and activities—create a difficult methodological challenge. Figure 2-1, p. 2-3, illustrates a range of techniques available to investigate possible characteristics and design choices for the future ATM system. This space of methods reveals a basic tradeoff: methods that are high on both dimensions in the figure can only be deployed relatively late in the development process and tend to be resource intensive. How can we generate the needed information to support decisions about the development of new ATM concepts and technologies in a cost-effective and timely manner?

In planning for the future of the AATT program, NASA needs to consider the appropriate mix and timing for using these different methods. We have been using methods that balance cost, timeliness, degree of control, face validity and environmental richness to provide input to system developers early in the design process. The methods we have used to support requirement identification are:

- empirical--collecting data about how people may carry out new roles and utilize possible new systems, thus helping to identify potential problems and define requirements for system development.
- scenario driven--rigorously exploring the implications of new ATM concepts and technologies by having different kinds of expert practitioners explore them in the context of concrete situations.
- iterative and converging--using multiple approaches that build on each other and converge on results that can support design decisions.

The end result for us has been an emphasis on different forms of CONCEPTUAL WALKTHROUGHS. In these conceptual walkthroughs, we posit a future ATM system, or parts of it, through development of a concrete scenario that instantiates a situation within that future system. We then collect data by asking aviation practitioners with different areas of expertise to evaluate or play out potential roles and interactions under that scenario, identifying how it could work and where it might be vulnerable. Report no. 2 in this volume describes these methods in detail.

1.2.2 Research Methods for Studying the Existing Aviation System

To understand the changes in human performance that may occur as we consider new ATM concepts and technologies, we have studied the effects of changes that are currently underway. Our work has drawn upon efforts focused on documenting and modeling performance in the existing system, with an emphasis on new FAA initiatives (the expanded National Route Program and the MAR program). This work has a broad systems perspective, examining how system elements interact in the context of real world factors. These studies of the existing ATM system are a rich stimulus for the development of scenarios to guide our exploration of the consequences of different technologies and designs on human performance in a future system. They provide a conceptual framework to guide the use of techniques such as conceptual walkthroughs. (See report no. 3 in this volume.)

Equally important, we believe that these studies, by taking a broad systems perspective, have served to provide important insights into how system elements are integrated and how they interact. Of particular importance is their emphasis on the impact of new technologies on the roles, responsibilities and interactions of the people using them, in terms of the regulatory environment, organizational behavior, and the different types of situations or scenarios that arise.

Recommendation 1: The AATT Program should continue to fund significant efforts to study and model the impact of changes currently being made or planned within the existing aviation system. These studies should take an integrated systems view in collecting and analyzing data, specifically addressing the interaction and coordination among the multiple agents within this system. These studies will help to further identify problem areas and provide objective data to guide decisions about future system development.

1.2.3 Research Tools for Studying Future Systems

Since the system of interest does not yet exist, we have used conceptual walkthroughs of possible future ATM worlds to study their impact on human roles, decisions, coordination requirements and information needs. In preparing for these conceptual walkthroughs, we developed scenarios that instantiate various generic issues or challenges for air traffic management and posit a hypothetical ATM world,

or parts of it, in terms of proposed technologies or procedures. Experts representing different roles and perspectives within the ATM system then think through or play out their potential roles, interactions and information needs within those scenarios. We do not provide detailed simulations; rather we ask the participants to describe in detail how such systems would have to function to provide support so that they could accomplish their tasks successfully. (Report no. 2 in this volume describes these methods in detail. See reports nos. 4 and 5 for examples of the data obtained from conceptual walkthroughs in this study.)

Critical to this method is the use of concrete scenarios to anchor the participants in the details of the coordination, communication, decision making and information exchange requirements necessary to handle the situation successfully. In addition, we have found that having multiple participants representing different perspectives about the ATM system maximizes the information generated by such scenario-driven conceptual walkthroughs. Anchoring people in concrete situations quickly reveals ambiguities about what their roles are and about how they would carry out those roles. Having people with different perspectives explore how to deal with these roles and interactions provides insights about how different people and organizations can coordinate to achieve all of the parties' goals for a safe, efficient and economical ATM system.

We have constructed a number of scenarios and used them in several conceptual walkthroughs to demonstrate the value of this approach. The scenarios developed to date address several kinds of issues for the development of future ATM systems such as transitions in method or locus of control (e.g., the transition from free flight rules to controlled airspace) and factors limiting system capacity (e.g., crossing traffic) among others. However, these scenarios represent only an initial exploration of the kinds of factors that should be considered.

Recommendation 2: Develop a set of scenarios that represents as fully as possible the range of tasks and situations that must be considered in designing components of a future aviation system.

1.2.3.1 Sample Scenarios

Given the importance of coordination among multiple agents in future ATM systems, scenario design was based on factors that pose challenges to such coordination within the system (see reports nos. 2 and 4). Some of these scenarios are derived from field observations, structured interviews and focus groups conducted as part of previous FAA and NASA funded research on the impact of the National Route Program (Smith, McCoy, Orasanu, et al., 1995). These particular scenarios focus on the impact of giving the airlines more flexibility in flight planning so that their business concerns can be better addressed. Other scenarios focus on components of a hypothetical free flight system, incorporating issues raised by the previous work of Sarter and Woods (1995) and Billings (1996) dealing with the impact of cockpit automation and air-to-ground communication technologies

on performance (see also report no. 7 in this volume). They involve operations in which a mix of free flight and controlled aircraft coexist, as is likely to be the case during the transition from the present to a future system.

1.2.4 Using These Tools To Evaluate System Designs

We have used the initial scenario set as the basis for several kinds of investigations to explore the potential impact of new ATM technologies on individual performance and on the coordination among multiple parties in the ATM system. The scenario set can eventually support more in-depth methods such as full or part scope simulation techniques as the AATT program matures.

1.2.4.1 Scenario-driven knowledge elicitation using subject-matter experts

We have used our scenarios to structure interviews with subject-matter experts, either singly or in a group. These subjects have been asked to comment on the likelihood of certain events given alternative future system designs, to predict the effects of such events on their operations, and to discuss ways in which they would avert the occurrence of such events or compensate for them if they did occur. Several scenarios have been explored (and refined) using this approach. (See report no. 3 in this volume.)

1.2.4.2 Conceptual walkthroughs using "future incident reports"

Scenarios have also been used as the basis for "incident reports" in which a future incident is predicted, and is presented in the form of a formal report investigating that incident (see report no. 4 in this volume). These incident reports, with supporting documentation, are presented to participants to consider as if they had actually occurred in some future system. The technique is used to structure a conceptual walkthrough by the participants, eliciting the ways in which the incidents might have been avoided, and how the system might be insulated against such occurrences or their effects. We have used this method to study how cooperative problem-solving in a hypothetical system can be facilitated, and how roles, responsibilities, procedures, policies and technologies must be designed to enhance performance and to make the system as error-tolerant as possible.

1.2.4.3 "Role-playing" conceptual walkthroughs

Another scenario was constructed to permit the observation of cooperative problem-solving more directly (see report no. 5 in this volume). Using this method, subjects are given the background and context of a scenario and the rules under which the system is operating. They are presented with the onset of an event and are asked to "play out" the scenario as it occurs, using a gaming board that represents the aircraft in particular ATC sectors. The participants can manipulate the gaming board to play out how the situation could evolve given different contingencies, actions, and interventions. Participants debate among themselves

different strategies for handling the situation. The methods by which they jointly resolve the problem are the data of interest.

Our research to date indicates that the use of these methods, based on concrete scenarios depicting incidents in hypothetical worlds, is a very effective approach for identifying critical issues that need to be addressed in considering specific design proposals.

Recommendation 3: As new designs (technologies, procedures, etc.) are proposed as part of the AATT Program, these three empirical methods should be applied early in the development process to assess the viability of each such proposal, and to identify the critical issues that must be addressed prior to its implementation.

1.3 Findings

We have applied the methods described above, working with a total of 40 controllers, dispatchers, pilots and traffic managers. Based on our studies, several recommendations have been developed about where to focus future research and development activities. These recommendations are outlined below. Note that our investigations to date have dealt primarily with situations that will challenge performance under future system designs from a safety and efficiency perspective.

1.3.1 Conflicting Goals and Capacity Constraints: Crossing Traffic

New ATM concepts shift authority and responsibility across different organizations. In particular, many of the ATM concepts currently being discussed decentralize and distribute authority for many decisions such as the planning and rerouting of flights. This decentralization creates the potential for cases in which the goals of different participants in the ATM system interact or conflict, and the requirement and opportunity to resolve the conflicts by negotiation. (See reports nos. 3 and 4 for detailed discussion of these issues.)

One such example that has already arisen as a result of the expanded NRP involves crossing traffic around major airports. A classic example of this arises with flights from Southern Florida to Minneapolis. With the introduction of the expanded NRP, the airline involved started filing such flights over Badger instead of over Iowa City-Waterloo. This put those flights in the departure lanes for traffic leaving Chicago O'Hare.

In the short run, the solution selected was to deny requests for this user preferred route, or to vector such flights around the area once airborne. The net result was a significant loss of efficiency for the impacted airline. In this case, work with controllers and traffic managers suggests that the limiting factor is controller workload. Solutions to eliminate this bottleneck must consider how to redefine

sectors to reduce workload, how to provide tools that enhance controller capabilities (again reducing workload), or how to redefine the rules for the use of such airspace.

A similar situation arose involving East-West traffic over Chicago. Under the expanded NRP, airlines started filing flight plans for this traffic over arrival and departure lanes. To resolve this problem, Chicago Center created new high altitude sectors. However, because there truly was a capacity limitation, in order to leave the NRP traffic untouched, arrivals and departures had to be restricted to lower than desired altitudes. The result is that fuel is saved by the overflights, but extra fuel is burned by arrivals and departures.

The significance of such examples to the AATT Program is twofold. First, the airlines are already telling us by their actions where some of the important bottlenecks are that will need to be addressed by improved technologies or procedures. Second, such examples are a reminder that the aviation system includes competition for limited resources by users, and that there will continue to be a need for procedures whereby some "referee" decides what is "fair" or what is best for overall system safety and performance.

Recommendation 4: Identify the types of situations where user preferences are likely to result in complex traffic patterns with crossing traffic, and explore solutions to eliminate the underlying causes of these bottlenecks. In addition, develop procedures to ensure safe, efficient, equitable handling of situations where such bottlenecks have not yet been successfully eliminated.

1.3.2 Conflicting Goals and Capacity Constraints: Cornerpost Loadings

Another capacity limiting situation involves the overloading of cornerposts at an airport. An example of this is the northwest cornerpost at DFW during peak hours. In the short run, providing AOCs with predicted loadings could help them to plan more effectively, avoiding expensive reroutings due to such overloading. In the long run, however, it would be preferable to eliminate the capacity limitation. Unlike the Chicago example above, though, enhancing controller performance (in this case using tools like CTAS) only partially deals with the problem. Although capacity can be increased with such tools, another limiting factor then comes into play: runway availability.

Recommendation 5: Explore solutions that minimize inefficient routings or vectoring to reduce cornerpost loading problems. Examine solutions that eliminate the underlying capacity constraints, as well as examining new decision support systems that make the most efficient use of the available capacity. (As one example, consider adding a "strategic" component to CTAS for earlier prediction and resolution of cornerpost loadings.)

Our data suggest that situations involving conflicting goals and capacity constraints represent a very important class of problems. It is important to identify the full

range of situations where conflicts like these can arise and to explore alternative solutions. Many of these solutions involve questions about how to support communication and coordination across different parts of the ATM system. Our data also suggest that these are quite challenging problems because they involve multiple parties and multiple goals.

1.3.3 Changing Roles and Information Requirements

Changing roles by redistributing authority (locus of control) has strong implications for the kinds of information and information displays needed to support these new roles (see report no. 4). New ATM concepts change the roles of many of the people involved in the system. Under some current proposals, dispatchers will have more flexibility in route planning; flight crews will play a greater role in ensuring separation; and controllers will act more as monitors, making new kinds of decisions about when to intervene. If the role changes created by these shifts in the locus of control, and in decisions concerning whether and when to intervene, are not accompanied by a corresponding shift in access to information, problems will arise.

1.3.3.1 Airlines and Flight Planning

A major problem in current operations is that the ATM system often has no access to information about the impact of its decisions on airline business concerns. As a result of this separation of authority and information, many decisions made by traffic managers and controllers are based solely on considerations regarding traffic flows and separation. Even when two solutions to a traffic problem are equally acceptable in terms of safety and traffic flow management, FAA staff generally do not have the information necessary to select a solution that might be preferable to an airline in terms of its business concerns.

As a response to such problems, the FAA has been shifting the locus of control to the airlines where possible. One example is with the expanded NRP, where (subject to certain constraints) the airlines are now allowed to file the routes that they prefer. The assumption is that, since the airlines have the information about their business needs, they are in a better position to make such decisions. On the other hand, although the airlines have information about their own business priorities, they have only limited information about air traffic bottlenecks. As a result, they must also make decisions based on inadequate information. As several airline air traffic coordinators and dispatchers have commented in our studies:

- “Under the expanded NRP, it’s like shooting ducks in the dark.”
- “The problem with the expanded NRP is that there’s no feedback to the AOCs. Nobody’s getting smarter. Someone has to be responsible for identifying and communicating constraints and bottlenecks.”
- “It used to be that weather was the biggest source of uncertainty for flight planning. Now it’s the air traffic system.”

Thus, whoever is given the authority to make strategic decisions about routing flights needs access to *all* of the pertinent information. The implication is that, when exploring future designs for the aviation system, one of the most important questions to be considered is how to effectively distribute and represent the information needed to support decisions.

1.3.3.2 Flight Crews and Separation

This same general issue arises in a tactical setting because of proposals to give flight crews more authority to change routes and altitudes while enroute. How do changing roles for flight crews and controllers affect who should have access to what types of information for tactical air traffic control decisions?

If pilots are sometimes to be given responsibility for maintaining separation in a free flight environment, then they and any available support software will have to play part of the role that controllers currently play (keeping in mind that, under current proposals, controllers will at a minimum still be monitoring the situation). They will have to detect potential conflict points in a timely fashion, generate solutions, and coordinate their actions with other aircraft.

Various studies of controllers indicate that they consider a number of complex factors including weather, the intentions of other aircraft, available contingencies, and positional uncertainty. In addition to considering the implications of these factors for their own flight, this new environment will require pilots to think about these factors as they impact other aircraft. New patterns of communication will also be required, as there will no longer be a single authority approving route and altitude changes (see report no. 7 in this volume). Furthermore, pilots will often have less knowledge than controllers do about typical traffic patterns in particular sectors, potentially making the cognitive demands on flight crews even greater.

Thus, our research has raised provocative questions about the roles of flight crews, controllers and support software in such an enroute free flight environment. It is clear that careful consideration must be given about who should have access to what information, about how wide a "field of view" each participant should have, and about how this information should be conveyed.

1.3.3.3 Controllers as Exception Handlers

Some of the new ATM concepts currently being considered suggest that in certain circumstances, controllers will act as monitors, detecting problems and intervening only as necessary to resolve specific concerns. The new roles have considerable implications for how controllers obtain the information they will need to carry out this role. Examples of controller statements during our studies help illustrate the complex issues that must be considered in proposing future system designs:

- “In adverse weather, communication occurs between controller and flight crews as needed. We ask: ‘When are you going to turn?’ and they say: ‘I can’t because weather is there.’ In that case I need to do something with someone else. If I can get him out of the way, I do it. The decision and evaluation process is 10 to 20 fold more complex as no structured game plan exists. It constantly changes as their needs change in each mile they go.”
- “For me to have the big picture or overview I need to know intent. Not knowing where the path is can be a problem. If I change your true path and another plane turns quickly, then we’re back into trouble.”
- “In free flight, nothing is preset. You will have to scan all the time. In the current system [there are] confliction points where [you expect] flows to cross on a daily basis. They are the spots you concern yourself with. You focus on confliction points. But in a free flight environment, everything is a focus point.”

There are many tasks and situations that must be dealt with to enable enroute free flight in situations involving multiple aircraft or unpredictable weather patterns. It is clear that such complex factors cannot be adequately handled by an autonomous machine agent in the foreseeable future, therefore any tools developed must be explicitly designed to support and enhance decision making by flight crews and controllers.

Recommendation 6: Identify the information and decision making requirements associated with new roles within proposed new ATM concepts. One tool for doing this is scenario-based walkthroughs that increase in level and scope of fidelity as the AATT project matures. The results will be important input for the development of new technologies as true decision support systems.

1.3.4 Coordination During Transitions in Level or Locus of Control

Another desired attribute of many proposed concepts for future ATM is flexibility. Under these proposals, flight paths and plans should be adjusted dynamically to best meet the rapidly changing demands and circumstances of the air traffic environment. ATC should intervene only when circumstances demand; otherwise individual operators should be able to plan flights and manage flight paths as they see fit based on their perspectives and goals.

This flexibility creates demands for coordination in several ways. Flight crews and ground controllers will have joint responsibility for positive separation. Locus of control will shift as circumstances demand. For example, traffic density in terminal areas will require transitions from free flight rules to greater control by ATC. How will these transitions be made smoothly? A major challenge for a more flexible and less centralized traffic management environment is the need to handle transitions in locus or level of control in order to cope with highly dynamic and unpredictable factors such as weather, emergencies and system failures. How will operators

recognize when circumstances create the need to shift locus of control? How will people communicate the change in management strategy and transition to a new form of control? Are there intermediate levels between full ATC control and full enroute free flight?

Our scenarios include situations where the locus or level of control must change in order to accommodate an event or environmental condition, thus allowing us to explore issues in successful coordination and cooperative problem-solving. Such transitions require highly effective coordination and communication between different people in the system and different computer based support systems. We also included a variety of elements that complicated communication and coordination, using these elements as probes to trigger discussion among the participants in the meeting about how to avoid or cope with such problems by means of new procedures, technologies or protocols.

1.3.4.1 Paradigms for Distributed Control

There is a variety of paradigms for distributing control. It is useful to consider three distinct paradigms as anchor points for exploring possible strategies in ATM. An actual system is likely to be based on intermediate strategies or a mixture of these. The first is "control by directive", where an agent in the ATM system (a controller, for example) simply issues an instruction which is to be followed (unless there is some overriding concern that prevents this). The second is "control by permission", in which the ATM system initially specifies a solution, but will consider and sometimes give assent to requests for alternatives submitted by system users. A third is "control by exception", in which system users are allowed to select and act on their own solutions or plans, which are then monitored by the ATM system for potential problems as these plans are enacted (see report no. 5 in this volume).

Within these paradigms there are a number of important variations that need to be carefully considered. For example, one extreme version of "control by exception" is to restrict interventions to localized, reactive responses by the ATM system. Under this variation, the ATM system would leave flights alone until and unless serious safety or system capacity problems were imminent. The assumption is that the users would generally select plans that avoided such situations so that interventions by the ATM system would be infrequent; it would function only as a backup safety net. Under another variation, the ATM system might play a more proactive role, dynamically setting certain constraints and communicating these constraints for the users to consider when they are comparing alternative plans. A third alternative would be for the ATM system to communicate a constraint by listing an explicit set of options for selection by the user. A fourth would be true collaborative control, where the users and the ATM system jointly assess the situation and consider alternatives. Numerous human factors issues arise in considering these alternatives:

- How do we ensure adequate involvement of various participants so that they maintain situation awareness, including continuous awareness of who is in control?
- How do we ensure adequate training and involvement of various participants so that they develop, and equally important, maintain the necessary skills?
- How can technology support the individual performance of controllers, dispatchers, pilots and traffic managers (assessing situations and monitoring for problems; generating and selecting from alternative solutions)?
- How will workload be predicted and managed given greater variability in the behavior of the system?
- In situations where there are goal conflicts, how do we ensure that adequate “refereeing” occurs (especially if the conflict has safety implications)?
- What types of roles should be assigned to participants so that, where appropriate, effective cooperative problem-solving will occur?
- How do we ensure that adequate mutual understanding develops regarding each participant’s goals, capabilities and constraints?
- How can new technologies support the communication of intent under both normal and contingency conditions?
- What types of tools should be developed to support cooperative work (e.g., tools to enhance a shared model or common ground; tools for graphic communication)?

The conceptual walkthroughs we have conducted provide results pertinent to these questions (see reports 4 and 5 in this volume). For example, the rules defining an operational error for violation of minimum separation standards will have an impact on when controllers will consider it necessary to assert more positive control on the aircraft they are monitoring. In regard to this issue, one of the controllers we studied indicated that if controllers were charged with operational errors when there was a violation of separation standards between aircraft operating under free flight rules, then controllers will not be able to wait for individual airplanes to sort out situations. Controllers will intervene and take control before such situations develop, rather than trusting flight crews to find resolutions on their own.

Although our research on coordination during transitions in the level or locus of control has begun to identify some of the factors that should be taken into account and to suggest some initial solutions, much work remains to be done to understand the impact of alternative control paradigms on individual performance, as well as on cooperative and (in some cases) competitive group performance.

Recommendation 7: Coordinated activity and cooperative problem-solving will be fundamental requirements in the implementation of the new ATM concepts currently under consideration. The AATT program needs to assess the potential impact of alternative methods of control and coordination on individual, group and overall system performance and to explore the design of tools for computer-supported cooperative work.

1.3.4.2 Communication Requirements During Transitions in Locus of Control

An environment in which pilots and controllers have joint or overlapping responsibility raises important issues about communication. For example, there is the potential for one party to act without adequate prior communication. Knowledge of intent may be difficult to maintain in these circumstances, yet knowledge of intent may be the critical information needed to anticipate potential problems. How will controllers monitor for potential problems if they cannot assume that they know the intentions of the aircraft they are monitoring? Thus, information on pilots' and controllers' intentions, decisions, and actions needs to be gathered and distributed very quickly to ensure that all affected parties are aware of changes in a timely fashion. (See reports nos. 7 and 8 in this volume.)

Similarly, once controllers recognize the need for intervention, how will they communicate this to all affected aircraft, providing assistance or asserting positive control over these aircraft and then returning them to free flight after the problem has been resolved? The pilots and controllers who participated in our studies agreed that successfully handling such situations in the future ATM system will require context-dependent, flexible and operator-controlled selection of communication media, protocols and strategies, while recognizing concerns about potential new demands on visual attention imposed by the introduction of additional displays.

Given the many competing demands for visual attention that already exist for both pilots and controllers, it will be critical to provide them with "big picture", status-at-a-glance displays that allow for parallel processing of various kinds of information. For example, the transition from enroute free flight to a more controlled environment potentially requires message acknowledgments by a large number of affected crews. These acknowledgments cannot be handled solely via voice communication as the controller may have to use the voice channel for issuing urgent clearances. Most controllers consider Data Link the medium of choice for those acknowledgments. But the implementation of digital communication for this purpose could create user problems. For example, users did not want to have to keep track of acknowledgments by referring to and monitoring a separate chronological message list. One possible solution proposed by some controllers is to visually code affected radar targets and their data blocks to indicate whether an acknowledgment has been received by the Data Link system. The goal would be to indicate acknowledgment in a way that would support pattern recognition.

In summary, communication demands, procedures, and technologies in the context of future highly flexible ATM operations are likely to differ considerably from those in the current highly standardized and more centralized ATC system. More insight is needed into the likely effects of introducing digital communication on the coordination between and among ground-based and airborne operators.

Recommendation 8: Examine scenarios involving transitions in method or locus of control to help assess the design of communications technologies and procedures. Specifically, the design of protocols and interfaces for a digital communication system needs to be reviewed and adapted to future ATM operations, since designs have been driven for the most part by the demands and characteristics of the current ATC system. One important goal is to avoid overloading visual attention during demanding situations and to enhance system transparency so that users can focus on what and to whom they want to communicate rather than focusing on the interface codes and commands needed to monitor and send messages.

Recommendation 9: Evaluate the potential for graphic communication tools for pilot-controller communications to coordinate interactions concerned with short-term flight plan modifications, weather phenomena and other potential hazards. Shared graphic tools are examples of computer-mediated cooperative work tools that could support transitions in locus of control, enhance shared situation awareness among flight crew, controllers and others, and support new controller roles to monitor and intervene only when needed.

1.3.5 Additional Specific Recommendations

Recommendations 4-9 deal with specific areas of concern that have been identified in our research, including issues dealing with conflicting goals and capacity constraints, changing roles and information requirements, coordination during transitions in the level or locus of control, and communication requirements during transitions in the locus of control. Several other specific recommendations arise from the interactions of these categories of issues. They are listed below.

Recommendation 10: Based on the scenarios studied to date, we recommend research on the human factors implications of a number of technologies:

- a) To support pre-flight planning by AOCs, predictive tools need to be developed to collect, analyze, disseminate and display air traffic bottleneck forecasts (analogous to weather forecasts) and to support plan generation. Even with the introduction of the expanded NRP, this is a major request by dispatchers. ("What we really need to make good decisions is NRP forecasts to help us decide where traffic congestion is likely to cost us time or fuel.")
- b) To support tactical planning while a flight is enroute, similar tools need to be developed to help pilots and dispatchers detect and deal with traffic and weather conflicts. Such tools would support the flight crew and dispatcher in considering complex factors such as the intentions of other aircraft and the availability of alternatives to deal with possible events. (A major question in designing these tools is how to provide an adequate field of view to support the detection and evaluation of developing situations.)

c) Tools need to be developed to provide information about the availability of special use airspace to support both strategic and tactical planning by flight crews and AOCs.

d) Tools need to be designed to provide controllers with information needed to monitor for potential problems, so that the controller can intervene in a timely fashion to help avert a potential loss of separation or provide advice on how to deal with a developing situation. This includes information about the intentions of flights. (The need to display intent may call for changes in aircraft flight management systems as well.)

e) Some situations will be too complex to allow enroute free flight. Tools must be designed to display the information necessary to help controllers and traffic managers predict and detect such situations, and to communicate to AOCs and flight crews those sectors that have been permanently or temporarily designated as "controlled" or non-free flight areas. (This is similar to issues currently faced in dealing with special use airspace.)

f) All of the above tools would help controllers, dispatchers, pilots, and traffic managers to deal with real-time problems as they are developing. Equally important are tools that provide feedback on performance. Tools need to be developed to help assess the success or failure of the strategies that various parties are applying, so that they can learn and improve.

Finally, there are several areas where current ATM procedures need careful investigation, looking for opportunities to provide the airlines with greater flexibility to accommodate their business needs. To make these feasible, it is likely that additional tools for computer-supported cooperative work need to be developed and studied.

Recommendation 11: Develop tools to support, and study the impact of, new ATM procedures that give the airlines more flexibility to deal with their business concerns, while ensuring safe and effective overall use of system capacity. Such procedures should deal with concerns about ground delay programs, severe weather routes, slot-swapping and runway assignments.

1.3.6 Other Conclusions and Recommendations

1.3.6.1 Training and Skill

The implementation of the expanded National Route Program has given rise to numerous misconceptions on the part of flight crew as to the purposes, policies, and procedures permitted or required under that program. (See pp. 3-8 and 3-9, page 3-17 and Observation 9 in report no. 3 in this volume.) These misunderstandings must remind us of the critical importance of training in a rapidly-changing environment.

Training will become even more important as further changes are implemented in the future aviation system. A lack of knowledge on the part of any class of participants can negate the gains in productivity or efficiency that such a change is intended to bring about, as shown in observations reported by our participants.

The misunderstandings reported here must also serve as reminders that training must be considered in the design of the future system. More distributed decision-making in the future system will require new procedures to ensure that all participants understand precisely how to determine who is in control of what, and how that control may be transferred among participants. This will involve new procedures which must be learned and understood. If pilots are to assume responsibilities for separation now exclusively the province of controllers, they will also have to learn what information is required, and how to use that information in making new decisions about flight path management.

Finally, controllers may find themselves managing the ATM system by exception (see report no. 5 in this volume), a role quite different from their accustomed role in the present system. This may also require the acquisition of new skills. It will certainly require that steps be taken to ensure their continued proficiency as controllers, though they may be actively controlling traffic much less than at present. The likelihood of skill decrements is real if controllers become less actively involved in traffic control and management.

Recommendation 12: ATM system designers must keep the training needs of controllers, pilots, dispatchers and traffic managers prominently in mind as they conceptualize and design the future ATM system. Guidance with respect to this issue will be required and should be a part of design requirements for the future system. Research like that reported here can be of help in developing training requirements for the future system.

1.3.6.2 Sharing of Information

A pervasive issue raised by the experts who took part in this study is the need for more information, more widely distributed, in a system in which decision-making is widely distributed. This issue was raised in every study conducted in this series. Exactly what information is required, and how it is to be represented to system participants under what circumstances, to permit wider distribution of decision authority, is less clear, yet answers to these questions will be crucial to effective system design. The scenarios used in these studies have illuminated some of the questions, but research will be required to obtain answers, and thus new system requirements.

Recommendation 13: *The AATT program should maintain a focus on research into information management and information requirements as it maps out the architecture of the future system. Some of the information requirements for decision-making regarding flight path control will be difficult to mechanize, and these will require particular attention by program managers.*

1.3.6.3 Philosophy, Policies and Procedures in the Future System

The architecture of the future ATM system is still unclear in many respects; that is the reason for the AATT program. Yet the design of the future system cannot be effective unless policy and procedural guidance is a part of the input to the design process. These studies point out how critical an understanding of participant needs is to formulation of design requirements for the future system. This complex, highly distributed system can only be effective if its architectural requirements are the drivers for the technological innovations that will be required in its realization.

Recommendation 14: The AATT program should work toward providing high-level conceptual goals, an operating philosophy, and a set of policies as guidance for designers of the future ATM system and of its components. It should sponsor further research specifically targeted at the development of a candidate philosophy, policies and possible procedures for the future system, in order to make the development process as coherent as possible.

1.4. Summary

The purpose of this report is to provide an indication of the conclusions we have reached based on our empirical studies under the AATT Program. Some of these recommendations are preliminary and incomplete. As we continue our data analyses, they will be refined, and new ones identified.

Generally speaking, our major theme is that it is important to evaluate new technologies early in the design process, and to do so in terms of the broader context of coordination and cooperation among the multiple agents within the aviation system. In conducting such evaluations, there are a number of factors that need to be considered, including:

- The constraints of the physical and operational environments;
- Philosophy, policies and procedures under which the system will be operated;
- Information that needs to be made available to various participants;
- Methods and technologies for distributing this information;
- Methods and technologies for supporting individual performance;
- Methods and technologies for supporting effective distributed, cooperative problem-solving.

Finally, it is critically important that we understand how different support technologies will influence human performance in the context of different situations or scenarios, especially scenarios where significant capacity constraints must be dealt with, and scenarios where transitions in the locus of control must be handled.

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HUMAN-CENTERED TECHNOLOGIES AND PROCEDURES FOR FUTURE AIR TRAFFIC MANAGEMENT

2. METHODS FOR THE DEVELOPMENT OF FUTURE SYSTEM REQUIREMENTS: THE ENVISIONED WORLD PROBLEM, THE FUTURE INCIDENT TECHNIQUE AND CONCEPTUAL WALKTHROUGHS

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2.1 Discovering Requirements for Future Systems

2.1.1 The Problem Of Envisioned Worlds

One important question for the AATT program is methodological: How can we identify system requirements for new ATM concepts and technologies, recognizing the potential for these changes to create new roles and procedures for individual participants, new forms of coordination across personnel and organizations, and new types of information to communicate, assess and integrate.

Developing functional requirements for human roles and support systems for such an envisioned world is difficult, in part, because the system of interest does not yet exist. There are no prototypes or mock-ups, and no practitioners who work in the future world. Usability testing is impossible: there is nothing to do it on and nobody to do it with. Yet, analyzing some of the cognitive ramifications and error opportunities in a future environment before any commitments to particular system designs are made is a tantalizing and potentially very fruitful prospect. How, then, can we gain access to a world that does not yet exist? How can an envisioned world be a source of data on the cognitive demands it imposes and the error and failure potential it creates?

The methodological problem is further complicated because different parties may have different visions of how the future world will work and because many details of the future system design are underspecified.

As an envisioned world, different developers, stakeholders and decision makers are each likely to develop their own insights and views on how the whole ATM system will work in the future. These visions can vary in perspective and degree of detail, since different stakeholders view the future world from different angles based on their role in the current system. In addition, stakeholders' views may be based on what they perceive to be the potential impact of the future world, as different groups of practitioners will have different stakes in what the future world will, or must, have in store for them, their positions, influence, job security, status, or roles.

As a result, at the early stages of conceptual development, there is (and must be) a diverse and loosely coupled collection of visions for the future. We refer to this aspect of the envisioned world problem as PLURALITY. Plurality means that there are many views that partially describe the future world. Since each comes from only the single perception of one group of practitioners or stakeholders, these views are necessarily partial representations of the ultimate complete and functioning system. Thus, to develop a coherent and complete set of functional requirements for human roles and support systems for an envisioned world one must integrate and rigorously explore all of the implications of these different viewpoints.

By definition, at an early stage of concept development many if not most details of the future system design are underspecified. The fact that developers are not bound by concrete, tangible roles, policies, and support systems can produce gaps and simplifications relative to the cognitive and cooperative work required of people in an envisioned ATM system. UNDERSPECIFICATION means that each of these single views is in itself a simplification, or partial representation of what it will mean for people to practice or carry out different roles when that envisioned world becomes concrete.

The fundamental underspecification that must exist in the early stages of a development process makes it easy for stakeholders to oversimplify the impact of a proposed concept on the roles, decisions, coordination needs, and information requirements of the people involved in ATM system.

These characteristics–

- an underspecified system concept,
- diverse but partial views of how the envisioned world might work,
- the potential to oversimplify the impact of design decisions on people's roles, responsibilities, and activities,

create the difficult methodological challenge that is the envisioned world problem. How do we design and test these new roles before committing large pools of resources? How can we assess the impact of new ATM concepts and technologies on

the individual and collective performances of controllers, dispatchers, flight crews and traffic managers? In other words, we need a model method to quickly prototype and study how people and technologies will coordinate in realistic operational scenarios for different ATM concepts.

Figure 2-1 illustrates a range of techniques available to us to investigate possible characteristics and design choices for the future ATM system. Two high level dimensions define the space of techniques. One refers to degree of control. The other refers to a correlated set of concepts of face validity, behavioral complexity, environmental richness (what is often referred to as real world fidelity or ecological validity). This space of methods was deliberately laid out to reveal a basic tradeoff: methods that are high on both dimensions in the figure can only be deployed relatively late in the development process, and they tend to be resource intensive. How do we generate the needed information to support decisions about the development of new ATM concepts and technologies in a cost-effective and timely manner?

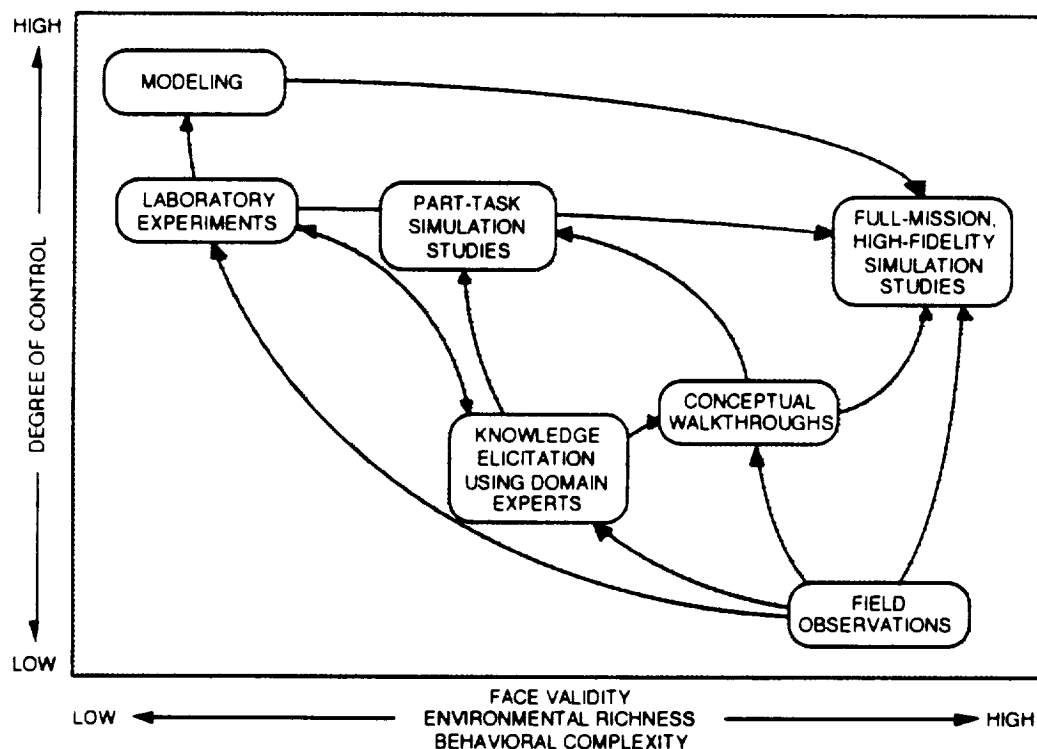


Figure 2-1: Potential research approaches. Methods high on both dimensions are resource intensive and generally become available relatively late in the development process.

2.1.2 Tools To Investigate Envisioned Worlds

To discover requirements for a future world, one needs to consider the appropriate mix and timing for using these different methods. In our work we have been using

methods that balance cost, timeliness, degree of control, face validity and environmental richness to provide useful input to system developers early in the design process. The methods that we have been exploring to support requirement identification for the ATM case are:

- empirical--collecting data about how people may carry out new roles and utilize possible new systems, thus helping to identify potential problems and define requirements for system development.
- scenario driven--rigorously exploring the implications of new ATM concepts and technologies by having different kinds of expert practitioners explore them in the context of concrete situations.
- iterative and converging--using multiple approaches that build on each other and converge on results that can support design decisions.

We have used three basic approaches to begin to develop human-centered requirements for future ATM concepts.

- *Knowledge Elicitation:* Scenario-driven knowledge elicitation using subject-matter experts.

One method that we have applied is to use scenarios to structure interviews with subject-matter experts, either singly or in a group. These subjects have been asked to comment on the likelihood of certain events occurring given alternative future system designs, to predict the effects of such events on their operations, and to discuss ways in which they would avert the occurrence of such events or compensate for them if they did occur. In applying this method, an effort is made to utilize subjects from different specialties, in order to elicit their different perspectives. Several scenarios have been explored (and refined) using this approach.

- *Future Incident Technique:* Conceptual walkthroughs using future "incident reports".

Scenarios have also been used as the basis for "incident reports" in which a future incident is predicted and is presented in the form of a formal report investigating that incident. These incident reports, with supporting documentation, are presented to participants (we have used groups of air traffic controllers, dispatchers and pilots) to consider as if they had actually occurred in a future system. The technique is used to structure a conceptual walkthrough by the participants, eliciting the ways in which the incidents might have been avoided and how the system might be insulated against such occurrences or their effects. We have used this method to study how cooperative problem-solving in a hypothetical system can be facilitated, and how roles, responsibilities, procedures, policies and technologies must be designed to enhance performance and to make the system as error-tolerant as possible.

- *Cognitive Walkthroughs:* "Role-playing" conceptual walkthroughs. Scenarios were also used to observe cooperative problem-solving more directly. Using this method, subjects are given the background and context of a scenario and the rules under which the ATM system is operating. They are presented

with the onset of an event and are then asked to “play out” the scenario as it occurs. The role playing is supported by a gaming board that represents the aircraft in particular ATC sectors. Participants can manipulate the gaming board to play out how the situation could evolve given different contingencies, actions, and interventions. Multiple participants debate among themselves different strategies for handling the situation. The methods by which they jointly resolve the problem are the data of interest. We believe this approach has considerable potential as a second method to conduct a conceptual walkthrough, eliciting additional insights concerning how various human and machine elements would interact in some future system.

Our research to date indicates that the use of these methods, based on concrete scenarios depicting incidents in hypothetical worlds, is a very effective approach for identifying critical issues that need to be addressed in considering design concepts and proposals.

2.1.3 Conceptual Walkthroughs

All of these techniques are based on CONCEPTUAL WALKTHROUGHS in different ways and to varying degrees. In these conceptual walkthroughs, we posit a future ATM system, or parts of it, through development of a concrete scenario that instantiates a situation within that future system. We collect data by asking a set of aviation practitioners with different areas of expertise to evaluate or play out potential roles and interactions under that scenario, identifying how it could work and where it might be vulnerable. In effect we try to turn plurality to our advantage by bringing together different kinds of practitioners with different perspectives to confront very concrete problem-solving scenarios in possible future ATM worlds. This is intended to reveal disjunctions and gaps across the various perspectives and elicit the cognitive demands that practitioners would confront during problem-solving situations in the envisioned world.

Critical to this method is the use of concrete scenarios to anchor participants to the coordination, communication, decision making and knowledge exchange functions necessary to handle the situation successfully. Rather than providing yet another (potentially underspecified) demonstration of how the future world would function, the scenarios are designed to challenge future architectures, to push on places where they may be vulnerable or to show how they may break down. Thus, the scenarios invite practitioners to think critically about the requirements for effective problem-solving in the envisioned world.

The conceptual walkthroughs, as a technique to cope with the envisioned world problem, sees today’s practitioners (pilots, controllers, dispatchers, air traffic managers) as a valuable source of expertise on solving problems in the airspace domain. Different kinds of practitioners bring different stakes and different problem-solving perspectives. Of course, when it comes to using their expertise to solve future problems, today’s practitioners are familiar with the role they play today and not with the role they may have to play in the future system. A pilot, for example, may have difficulty assuming responsibility for separation in his new free

flight role, just as a controller may have reservations about relinquishing separation authority. The key is not to rely on the participants' opinions about the future, but to use the scenarios to help them reveal the constraints that will need to be met to make a future system work well in terms of cognitive and cooperative activities.

The value of the conceptual walkthrough depends on the construction of effective scenarios. Concrete, challenging scenarios serve as a mechanism to explore the dynamic interplay of cognitive activities and demands associated with different problems that can occur and unfold in the envisioned world. A good future incident provides a compelling demonstration of the cognitive work required to operate successfully with new roles and rules in the envisioned problem-solving environment. The scenarios then are not simply "interesting" cases, but represent an instantiation of factors that may play an important role in the future system. For example, the scenarios used in this work create concrete instances where a future ATM system must shift from one form of control to another (from less to more controlled air space). Another example is a specific case where different parties have different but conflicting goals (e.g., enroute traffic crossing a departing stream).

To provide useful results relative to an envisioned world, the conceptual walkthroughs should involve a set of participants with different perspectives who can challenge each other's proposals if they are underspecified or if they are incompatible with the demands and goals of another part of the overall system. These disjoints occur naturally as diverse participants confront challenging cases, and help identify system requirements.

We have used two strategies to confront expert practitioners with concrete problem-solving situations: the FUTURE INCIDENT TECHNIQUE and COGNITIVE WALKTHROUGHS of future problem-solving situations. The Future Incident Technique has practitioners provide a retrospective analysis of a reported incident that might occur in a future ATM world. The report describes an incident that has taken place one or two years from now (where now is 1996) in a possible future ATM system. The hypothetical reports forms shown on pages 21-23 show one such future incident report. Participating practitioners are asked to evaluate the report as neutral observers (Woods, Cook, Johannesen & Sarter, 1994), i.e., as domain experts who are not caught up in the evolving problem-solving context, but who can offer problem-solving strategies in comparison to those used by practitioners in the incident.

In contrast, cognitive walkthroughs of future problem-solving situations provide participating practitioners with the initial conditions of a situation that have the potential to concatenate and evolve into an incident. Several different practitioners are invited to participate in solving future problems, under guidance of a researcher. The practitioners are seated around a representation of a piece of airspace, the "game board" (see Figure 2-2). The initial conditions of the problem are portrayed on a game board that represents a God's eye view of a piece of airspace with aircraft in it (not unlike the "shrimp boat" tables that were used prior to radar-based air traffic control; Nolan, 1994).



Figure 2-2: The set-up for the cognitive walkthroughs of future problem-solving situations.

Aircraft on the game board are annotated (to display their call signs and altitudes) as they are on today's PVDs - with the exception of cleared altitudes since those will not be available in free flight. Practitioners are asked to take the initial conditions and to verbalize and discuss with one another the ways in which they want to solve the problems that could ensue from the initial conditions. Specific solution strategies (directives, clearances, airspace changes, etc.) can be marked on the game-board and are used as a trace of problem-solving behavior (see Figure 2-3). Additional probes (extra complicating factors, for instance) are inserted as the scenario unfolds.

In the Future Incident Technique, practitioners are confronted by a near miss or failure. The fact that the system has not functioned completely successfully reframes the envisioning process. Instead of thinking about how a future concept might work, the participants are forced to consider how the system might break down. This can lead them to identify the cognitive and coordination demands that need to be supported to make the concept robust and successful in the real operational environment. The incident is worked out *a priori*, and in its entirety, including the outcome. Thus, participants discussion may be limited because they see a single path and have knowledge of an outcome.



Figure 2-3: The game board used during the cognitive walkthroughs of future problem solving situations; pilots and controllers are discussing and pointing to a particular problem.

In contrast, during cognitive walkthroughs, practitioners are caught up in the evolving incident. The outcome is not known, not even to the investigator. Before the cognitive walkthrough, practitioners are prepared for their new roles and rules through briefings and handbook excerpts, etc. In addition, changing rules are instantiated as background characteristics or complicating factors (for example: aircraft will not necessarily exit free flight airspace neatly across one particular waypoint). Other complicating events and factors are inserted during the evolution and treatment of the incident (for example: a communications failure may occur, or a thunderstorm may crop up), in order to challenge and put pressure on particular rules or roles.

These two approaches provide converging evidence about the roles, responsibilities, cooperative activity, judgments, communication and areas for support in a possible future world.

2.1.4 Verbal reports of problem-solving strategies reveal differences that serve as a source of data on cognitive demands

As different expert practitioners (pilots, controllers, dispatchers) assess concrete, detailed future problem-solving situations, the data of interest are the disjunctions and gaps among the individual interpretations and problem-solving strategies. The disjunctions between the various interpretations and perspectives often point to the demands and potential bottlenecks in a possible future ATM system. Data on these disjunctions consist of verbal reports on problem-solving during the incident scenarios (Ericsson & Simon, 1993; Woods, 1993) from audio recordings supple-

mented by video recording of the interactions with the gaming area for the cognitive walkthroughs.

When confronted with other perspectives, however, the differences in problem-solving strategies and the disjoints in how practitioners perceive the envisioned system can reveal the following:

- places where pieces of *knowledge* to solve a problem may be unavailable (e.g., a controller may want aircraft intent, but according to a pilot it may not be accessible given the nature of his operations at that moment);
- times when different *goals* come into conflict (e.g., a dispatcher may want a pilot to use his free flight flexibility to go to a particular airport, but the pilot will divert somewhere else, or a controller may want a pilot to go through a weather system to solve one of his own problems, but the pilot will not do it);
- situations in which *attention* must be distributed across different or very large portions of the problem-solving world (e.g., the controller may simply want to get a number of aircraft off free flight, but the flight crews will want to know the specific headings, altitudes, and speeds they should fly once taken off free flight).

In the reports, these knowledge, strategic and attentional demands can be referred to by statements of how difficult it may be to accomplish a certain activity, but also by suggestions of strategies or system changes that would help attenuate this difficulty. Disjunctions not only reveal underspecification in individual interpretations, they also reveal hard constraints and problems that the future system will have to deal with. This means that if the different practitioners are able to reach consensus on resolution of the incident problems after the specifics of the future mishap have been brought to light and been battled over, then this can point to more robust suggestions for the design of better specified procedural or technological support.

2.2 Scenarios

Given the importance of coordination among multiple agents in future ATM systems, scenario design was based on factors that pose challenges to such coordination within the system. For example, we considered factors that create the need for timely communication and coordination between multiple agents, factors that create the need for updated situation assessments and decisions, and factors that lead to conflicting goals.

Some of these scenarios are derived from field observations, structured interviews and focus groups conducted as part of previous FAA and NASA funded research on the impact of the National Route Program (NRP) as initially defined in Advisory Circular 90-91, and more recently modified under orders defining the expanded NRP (Smith, McCoy, Orasanu, et al., 1995). These particular scenarios focus on the impact of giving the airlines more flexibility in flight planning so that their business concerns can be better addressed.

The initial scenario set can be used to support many different activities. We have used them as the basis for several different kinds of investigations to explore the potential impact of new ATM technologies on individual performance and on the coordination among multiple parties in the ATM system. The scenario set can eventually support more in-depth methods such as full or part scope simulation techniques as the AATT program matures.

2.2.1 Probes for Knowledge Elicitation

2.2.1.1 Basis for Scenarios and Observations

The goal of this set of scenarios is to focus attention on preflight planning at the airlines, and on the implications of such planning for air traffic management and control, with an emphasis on human factors issues. This scenario set was used to begin to address the following questions:

1. What rules and procedures should be adopted to govern the behaviors of the airlines and the Air Traffic Management (ATM) system during preflight planning activities? How will these rules and procedures deal with current concerns? Will they create any potential new concerns?
2. What rules and procedures should be adopted to govern the behavior of air traffic (including military, general aviation and commercial aviation traffic) and the actions of traffic managers while flights are enroute in order to allow them to deal with situations that may arise as a result of the rules governing preflight planning?
3. What roles and responsibilities should be assigned to different individuals at the airlines and within the ATM system? What training is necessary to ensure effective performance in these roles?
4. What services should the ATM system provide to the airlines?
5. What information should be exchanged between the ATM system and the airlines (both real-time and historical information)?
6. What technologies need to be developed to effectively support these roles and responsibilities?

The scenario set is based on some high level issues including

- factors that lead to conflicting goals,
- factors that create the need for updated situation assessments and decisions,
- the dynamics of the airspace flows and capacities,
- factors that create the need for cooperation across multiple interacting organizations and individuals,
- the distribution of information across multiple interacting organizations and individuals in anticipating, detecting or responding to problems,
- situations where feedback about results of policies and decisions is needed to ensure system and organizational goals are met.

The scenario set below is based on some high level issues such as goal conflicts, the dynamics of the airspace flows and capacities, strategic issues, cooperation across multiple interacting organizations and individuals, feedback about results of policies and decisions. (Detailed findings from experiments using this set of scenarios are discussed in report no. 3 in this volume.)

2.2.1.2 Scenarios to Guide Knowledge Elicitation

ATM Background

To help make the discussion concrete, we are going to use the ATM system as it existed from January 9, 1995 to December 31, 1995 as our "scenario." The basic question is: What can we learn from experiences that arose during the initial implementation of the expanded NRP in order to guide us in future decisions about the design and implementation of the ATM system?

The Scenario Set

Observation 1. Data from one major airline indicated that the increased flexibility in flight planning provided during the first three months under the expanded NRP allowed its dispatchers to file flight plans with the potential to improve fuel efficiency by 2.5%.

Observation 2. As stated by a TMO, "The MAR program and the NRP program have been beneficial in a way. They have shown us a lot of places where we might have been a little comfortable. I've seen a lot of places where they've cut away some of the fat out there. We've almost eliminated our miles-in-trail restrictions at Oakland Center, for example. But I think we've reached the level we can handle with the technology we have today."

Observation 3. The expanded NRP gave the airlines more flexibility and control in selecting the routes for certain flights. It did not provide the airlines with any increased flexibility as far as ground stops were concerned.

Observation 4. Because of a closed runway, the arrival rate into LaGuardia for the next 3 hours was restricted to 75% of the normal rate. ATCSCC put a ground stop program into effect, holding a number of flights at other airports on the ground. Several affected airlines wanted to substitute some of their delayed flights for others that were still scheduled to leave on time, as these delayed flights were much more time-critical in terms of passenger loads and connecting flights. The ATM system had no easy mechanism to accommodate this desire.

Observation 5. Traffic from the west into the northwest cornerpost at Chicago was very heavy. Consequently, this traffic was being sequenced to ensure efficient landings at O'Hare. When one airline wanted to file a flight from Minneapolis to

Chicago, rather than simply telling the airline that the flight would be delayed for 20 minutes on the ground, the ATM system gave it a choice: "You can take a 20 minute ground delay and then be assured that you can be sequenced into the flow at the northwest cornerpost, or you can take off now with a 20% chance of being fit into that sequencing and an 80% chance that you will be vectored to the northeast cornerpost instead." The airline decided for business reasons to go ahead and launch the flight.

Observation 6. The expanded NRP raised certain concerns at some (but not all) Centers. As an example, one challenge arising from the expanded NRP was that airlines sometimes wanted to cross their high altitude flights over departure and arrival routes. Such flights criss-crossed through the departure lanes, creating a "very tricky, complex operation" for ATC. This raised an interesting question: Do you let 3 or 4 planes cross at the cost of slowing departures by about 20%? This tradeoff was particularly interesting because such flights were most often slowing departures from Chicago of flights by two other airlines.

In contrast, at Oakland Center such criss-crossing traffic through arrival lanes is being allowed, but not without significant concern.

Another concern introduced by the expanded NRP was due to the instruction to give preference to NRP flights. As one TMO stated: "It gets cumbersome because the NRP program says you're not supposed to touch them. So we have to move 3 or 4 other airplanes to solve one problem. They [the Command Center] encourage you to move other traffic to leave the NRP traffic alone."

A fourth example that arose as a direct result of the expanded NRP at some airports, and also as a result of an increased numbers of direct flights, had to do with balancing of loads at cornerposts: "If we get a jetstream right out of the southwest part of the country, everyone rides it [into O'Hare]. 75 percent of these airplanes are all coming in at the southwest cornerpost, creating a major volume saturation point.

A sixth example of an issue associated with the expanded NRP concerned what was happening when there were arrival rate restrictions (due to weather, etc.).

Observation 7. At certain Enroute Centers such as Chicago and Cleveland, numerous examples were noted where new problems with air traffic congestion arose. It is important to note, however, that many of these concerns did not arise because of the preflight plans filed under the expanded NRP. As one TMO reported: The source of the major concerns was not the expanded NRP per se; it was the spin-offs of the expanded NRP, such as the increase in direct routes that were filed while flights were enroute. The impact was that flights were now going direct through sectors where they had not done so in the past. Specifically, once airborne, pilots were requesting and getting clearances for direct routes from controllers, who were clearing them on these direct routes without any approval from the affected sectors.

This was apparently interpreted by these controllers as the "Free Flight" concept. (The actual order for the expanded NRP contained no such instructions.)

There was also a problem with the unpredictability of traffic loads from day to day. In terms of the magnitude of this problem, 70 to 80% of the flights over many Centers were now on direct routes. For some Centers, such as Kansas City and west, this wasn't a major problem. For others like Chicago and east, there was a significant impact. Some aircraft had to be held at the Chicago Center, Cleveland Center, and Indianapolis Center boundaries because sequencing the resultant multiple flows became nearly impossible.

Observation 8. Another potential challenge was a concern with commuter flights. With aircraft like the Challenger jets, "they want to go to 37,000 feet." How will this traffic be handled if they start to take advantage of the expanded NRP?

Observation 9. As indicated above, pilots as well as controllers contributed to this sudden increase in direct flights. Pilots (with the permission of controllers) chose to fly direct instead of flying the route selected as "optimal" during preflight planning. A contributing factor in examples of this problem appeared to be a lack of awareness by pilots as to when they were on an NRP flight plan. Interviews with pilots from several airlines indicated that they did not know when they were flying a flight plan filed under the expanded NRP.

Observation 10. A Dispatcher had a choice between filing a flight from LAX to DFW either north or south of White Sands. The northern deviation offered the shorter wind route. When the flight approached the northwest cornerpost for Dallas, however, the flight was vectored to the southwest cornerpost because of traffic congestion. As a result, the flight burned substantially more fuel and was later than it would have been if it had originally filed the southern route to the southwest cornerpost.

Observation 11. A number of airline dispatchers and ATC coordinators were completely unaware of the dramatic increase in direct flights that occurred following the implementation of the expanded NRP (even though flights from their own airlines were involved).

Observation 12. The system for requesting non-pref routes through ATCSCC under the old NRP (Advisory Circular 90-91) provided an example of how procedures can be established to encourage the distribution of knowledge to relevant participants in the flight planning process. As one airline ATC coordinator stated: "When we started this [the procedure for requesting non-pref routes], even Central Flow didn't know where all the choke points were. But as we pressed the system ... Originally, we'd call and they'd say no. But then it became: 'Well, if you would just do this, if you'd just make this minor adjustment in your flight plan, we could probably do this. It became a much more collaborative effort."

Observation 13. In contrast, 6 months later, after the start of the expanded NRP, this same ATC Coordinator noted: "The problem with the expanded NRP is that there's no feedback to the AOCs. Nobody's getting smarter. ... When we went to free flight on Jan. 9, we cut off the feedback loop for those flights filed under the expanded NRP. ... How do we get this local knowledge that the TMUs and controllers have out there for the dispatchers and pilots? ... There are problems in the ATC system that I don't know about. I need a mechanism to get feedback. ...

Observation 14. The assumption behind free flight is that "if the airlines create a bottleneck and for 3 days in a row they get delayed, they'll change. The assumption, in other words, is that free flight represents a "free market" environment in which businesses will respond to problems in order to remain competitive. Upon implementation of the expanded NRP, however, new problems arose that resulted in consistent inefficiencies for certain flights. The airlines were often very slow to respond, however, taking weeks to recognize and react to such problems.

Observation 15. TMO: "We don't even get a listing of who flew NRP the day before so we can review it and see what are the trends."

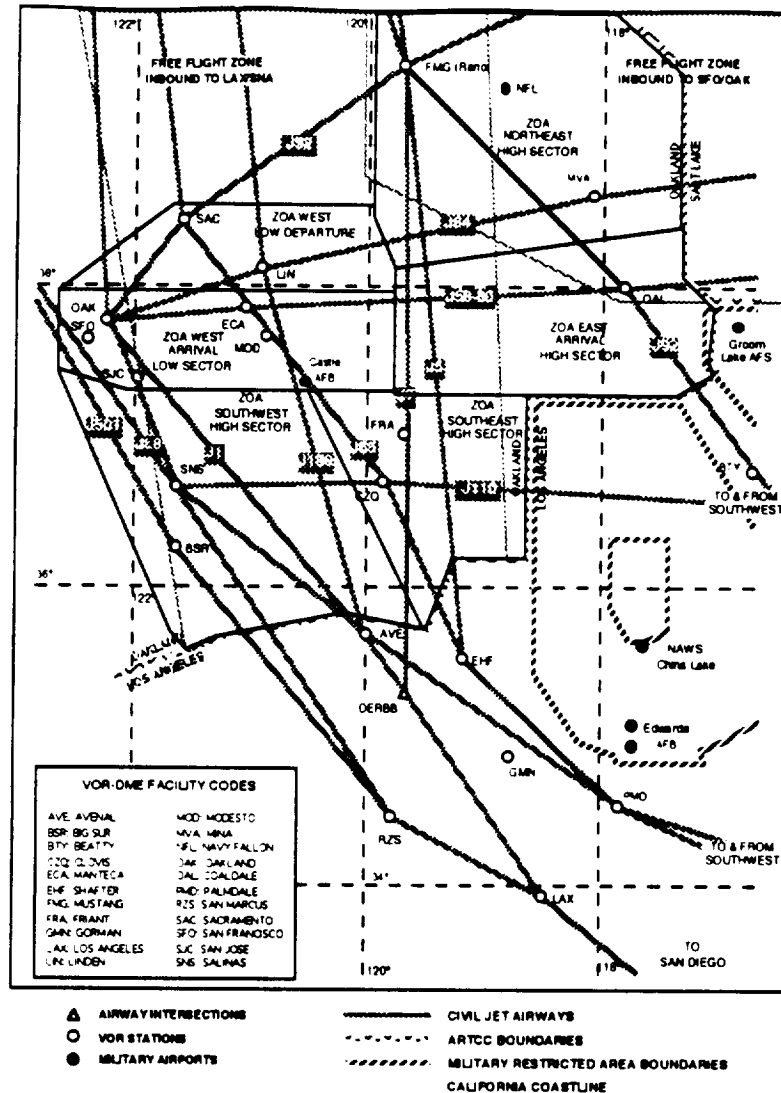
2.2.2 Scenarios for Future Incidents and Cognitive Walkthroughs: the Gaming Area

The scenarios developed for the Future Incident Technique and for the Cognitive Walkthrough were based on a common "gaming" area (Figure 2-4). An area was chosen in the contiguous United States, (roughly between 34° and 40° north latitude and 116° and 122° west longitude) that ranges from Los Angeles in the south to Reno in the north and from Coaldale, Nevada in the east to the California coastline in the west (see Figure 6). This area was chosen because of several characteristics that can accommodate many of the identified problems and constraints:

- prohibited and restricted areas (military and special use airspace) that restricts the room to maneuver both for individual aircraft and the airspace manager;
- the potential presence of military traffic asking for priority clearances;
- periods of high traffic load, all of which is competing for the same airspace as it approaches San Francisco, creating a funnel of in-flowing aircraft;
- north-south traffic to and from Los Angeles that may be in free flight and crosses the stream of traffic coming into the Bay Area;
- the opportunity for several weather phenomena (thunderstorms being pushed up against the Sierra Nevada; clear air turbulence at altitude).

Some of the rule changes that were used as probes in this research were instantiated as constants in the gaming area itself. For instance, the free flight zones inbound to (and outbound from) Oakland and Los Angeles do not exist today, and represent major differences as compared with today's situation.

Figure 2-3: Gaming area used in these scenarios



Glossary for the gaming area:

Advisory	non-binding information from ATC to flight crews concerning other traffic that is in the area.
DEN	Denver International Airport
FL	Flight level (FL320 is 32,000 ft; also referred to as "320" or "32").
FMS	Flight Management System (on board most modern air transport aircraft).
OAL	Coaldale VOR, a waypoint for traffic inbound to San Francisco.
PIT	Pittsburgh International Airport
RA	Resolution Advisory, generated by TCAS
TA	Traffic Advisory, generated by TCAS
TCAS	Traffic Alert and Collision Avoidance System (on board aircraft).
TOD	Top Of Descent (the transition from cruise flight to descent)
Transponder	On-board receiver/transmitter which will generate a reply signal upon proper interrogation. Only when the transponder is in "Mode C" will the reply signal contain the altitude of the aircraft being interrogated. Mode C (or Mode S) transponding is the basis for TCAS.
VOR	VHF OmniRange (a ground-based radio navigation beacon)
Waypoint	point along airway, often a VOR or an airport
ZOA	Oakland Air Route Traffic Control Center
z	Zulu time (also: Universal Time Coordinated, or UTC)

2.2.2 The Scenarios: Future Incident Reports

In the conceptual walkthroughs of future incident reports, incidents that might occur and problems that might arise in a future Air Traffic Management (ATM) system are used to stimulate input from a group of people who play diverse roles in the current ATM system. These possible incidents are reported as if they had occurred in an incident report format including the sequence of events and why the problem may have occurred. The incident reports are used to structure discussions among experts (pilots, air traffic controllers, dispatchers, air traffic coordinators and traffic management unit coordinators) about the incidents themselves, the context, the roles of the different people and machines in the incident, the implications for future procedures and technologies, and the implications for future ATM systems. The method is designed to generate information quickly and efficiently on human-machine and human-human cooperation to help the aviation community move towards a new and more effective ATM system.

Three incident report scenarios have been constructed, criticized and tested. The first is the baseline case; the second extends the first incident through the addition of an unanticipated disruption in the airspace (military traffic). See report no. 4 in this volume for discussion of the results obtained with these scenarios.

2.2.3 Scenario Basis

The scenarios were designed to include several major factors. First, there is a mixed locus of control, that is, there is a mix of controlled traffic and free flight traffic in the sector. This is done by including traffic that is transitioning from free flight to ATC control as they reach a point where they begin to be lined up for descent into the San Francisco area airports due to traffic density. At the same time there is a crossing stream of high altitude traffic operating under Free flight.

Second, the traffic pattern overall is congested and complex creating heavy controller workload.

Third, the scenarios were designed to create situations where there may be some transition in mode of control (variations from full free flight to more ATC control). One of the major challenges for a more flexible and less centralized traffic management environment is the need to be able to handle transitions in mode of control in order to cope with highly dynamic and unpredictable factors such as weather, emergencies, system failures. The scenarios were designed to represent examples of circumstances/events that could make such a transition necessary. In the baseline scenario an encounter with turbulence affects a number of surrounding aircraft, changing the entire traffic configuration and creating the potential for ATC intervention. This creates a unanticipated situation where several aircraft begin to change their flight paths by more or less simultaneous maneuvers (as opposed to the serial creation of orderly traffic flows by a controller). The traffic pattern is

sufficiently complex that controllers may need to intervene to avoid problems. In the next incident an unanticipated transition in control is created by the need for priority handling of the military refueling in a free flight environment.

Such transitions require highly effective coordination and communication between human(s) and machine(s) in the system. The scenarios focus on how this coordination and communication can break down for a variety of reasons some of which are included in the incidents: a stuck mike (no method of communication), a failed transponder (lack of important information for separation), a delayed response by a crew to a controller instruction in part related to assumptions about the protocol for digital communication, the lack of coordination between machine (TCAS) and controller instructions to crews, the lack of acknowledgments by some aircraft in response to the controller's broadcast message concerning the necessary transition in the 2nd scenario, etc. These events are introduced as probes to trigger a discussion with the participants in the meeting about how to avoid or cope with such problems by means of new procedures, technologies, and protocols.

The issue of distributed decision making and responsibility is introduced by assuming an environment in which both pilots and controllers are supposed to maintain awareness and take necessary actions based on airborne and ground-based system information without the explicit need for communication before action. This may create problems for the controller who needs to create a picture of the traffic but without knowing intent and without being able to assume that the only thing that will change the picture (in predictable ways) are his own instructions.

Another issue addressed by these scenarios is how controllers, as a kind of backup system, will maintain or regain awareness of the traffic situation. Here the challenge occurs based on the large number of aircraft and the complexity of traffic flows in that area, the mixture of aircraft equipment which makes it more difficult for the controller to know what clearances can be accepted/handled by whom and how well, and how to communicate with aircraft (some data link, others voice), the additional challenge of working with a conflict resolution and advisory system.

The third future incident was created to investigate the knowledge demands and goal trade-offs that are associated with the role of a pilot actively seeking his way through airspace, how dispatch can aid in making decisions, and whether minimizing the risk of ATC restrictions would be one of the goals of the flight crew.

In the third incident, two aircraft are inbound for SFO under free flight rules. One of them, from DEN, asked ZOA for an advisory on crossing traffic to and from LAX, and initiated a right turn in order to avoid heavy crossing traffic. This brought the aircraft into conflict with another aircraft, inbound from PIT. Unwilling to climb, the PIT aircraft was late in reacting to a TCAS RA and safe separation was lost. This incident involved goal trade-offs for both aircraft: for one, the risk of conflicts vs. the cost of a hold, for the other, the risk of not making its destination because of low fuel and the risk of a loss of separation by a late response to a resolution advisory.

2.2.4 The Future Incidents

Presented here are the specific documents and incident reports that were used in the conceptual walkthroughs of Future Incident Reports. They include a briefing guide, excerpts from Advisory Circulars and the Controller's handbook which provide background for the ATM policies and rules in operation in the ATM system at the time of the third incident, and voice transcripts and an ASRS *Callback* excerpt.

The documents include:

	<u>Page</u>
• A scenario participant briefing for the first and second incidents	2-19
• First incident report used for retrospective analysis, 4/1997	2-20
• Second incident report used for retrospective analysis, 11/97	2-23
• Advisory Circular excerpt applicable to the third incident	2-26
• Controller Handbook excerpt applicable to the third incident	2-27
• Third incident report used for retrospective analysis. 1/98	2-28
• Cockpit voice recorder transcripts from the third incident	2-31
• NASA ASRS Callback excerpt	2-34

Note: the documents on pages 2-19 through 2-34 are not real. They were created in 1995-1996 in the Cognitive Systems Engineering Laboratory at the Ohio State University for the purpose of the research outlined in this report.

Scenario Briefing

Background

These scenarios take place in 1997 in Oakland Center airspace. The free flight concept has been implemented in enroute airspace, though terminal areas are still under ATC control and many aircraft are still not fully equipped for free flight. Some do not have data link, though all aircraft are equipped with TCAS-2 and Mode S transponders. Older aircraft do not have flight management systems, and the VOR/DME airway system is still fully operational for aircraft which require it.

Those aircraft which are equipped and choose to utilize free flight must still file flight plans to inform ATC of their intentions, but they do not require clearance to execute those flight plans and they are permitted to deviate from their original plan as required for the efficient conduct of their operations. They are expected to notify ATC of such deviations. Air Traffic Control facilities monitor all IFR aircraft, as they do today, but ATC will intervene with a free flight airplane only if it observes a potential conflict. Pilots are also expected to maintain traffic surveillance; TCAS-2 with extended range is the system by which they observe traffic likely to come into conflict with their flights.

Situation

The two scenarios are duplicates; they differ only in complexity. Both take place during the period 2350-0020Z (1550-1620 PST), though on different dates. The weather in the vicinity of Coaldale involves scattered to broken decks of cirrus clouds between flight level 240 and 340; winds at those altitudes are 290° at 40-60 knots. Light to moderate turbulence has been reported by pilots at all altitudes between FL 300 and 390.

In each scenario, inbound traffic arriving from the east over Coaldale, the point of transition from free flight to positive control, is moderate and becoming heavier. Southbound traffic enroute to Los Angeles is still relatively light; northbound traffic is moderate. In the 2nd scenario, the traffic situation is complicated by the need for an emergency refueling of a military aircraft with hydraulic problems.

Traffic in the area is under the surveillance and control of Oakland Center; the Center boundaries are shown in the incident reports. In the first scenario, conflict probe and resolution advisory software have recently been approved for operational use. In the second scenario, this software modules are approved for use under most weather conditions. Conflict probe is an automated system that evaluates (at this time in its development) possible conflicts occurring within five minutes; the resolution advisory module suggests avoidance maneuvers or flight path amendments to the controller. If the controller approves a suggested flight path change, it will be transmitted via data link to equipped aircraft, whose pilots will execute it manually or through their flight management systems. In aircraft without this equipment, the controller will issue amended clearances by voice. Equipped aircraft may also notify ATC of flight path changes by data link.

ATC FREE FLIGHT INCIDENT REPORT

DATE: 04/26/97

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This form will be used to report incidents involving aircraft in free flight as defined in Handbook 1165.1. Reports will be completed within five days of occurrence and sent by fax to ATP-100. Appendices may be forwarded by ordinary mail.

1. SUMMARY (Include graphics as necessary)

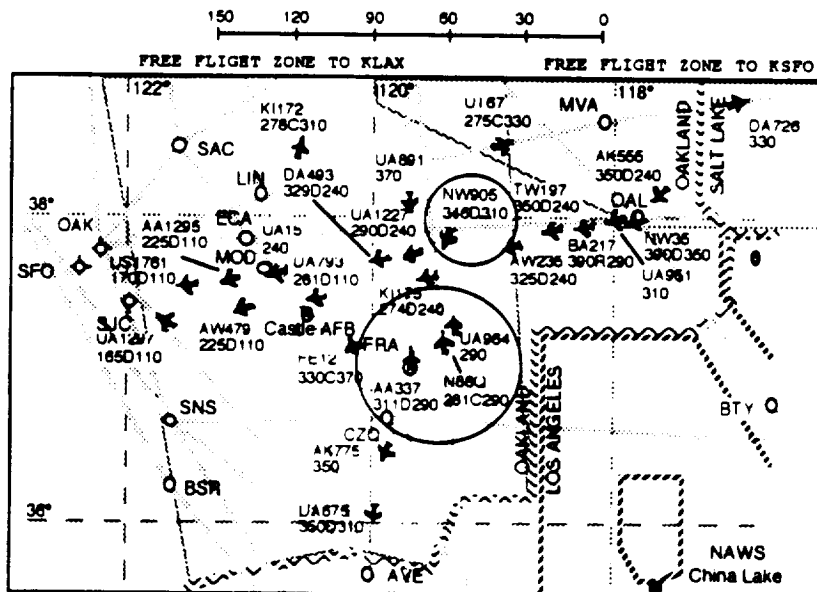
SUMMARY: At approximately 0017Z (1617 PST) on Friday, November 11, 1997, an incident occurred on airway J5 about 20 miles south of J80. The incident involved three civil aircraft northbound, two on free flight direct routes, and one aircraft southwestbound, also in free flight. All were under the surveillance of Oakland Center, which was also handling two streams of inbound traffic to KSFO and KOAK via CEDES and SUNOL.

The responsible controller and the conflict detection system both detected the conflicts and provided resolution advisories which were forwarded to the aircraft. One advisory was too late to prevent a loss of standard separation; one was not acted upon in timely fashion by the affected aircraft.

This incident was caused by a combination of circumstances: the conflict detection system did not predict one conflict soon enough to provide a timely resolution advisory; the controller, who was heavily loaded at the time, lost awareness of the effects of the clearance provided to one aircraft and foresaw the potential conflict to the other civil aircraft too late to provide a timely diversion. Contributing factors were the failure of the flight crew of one civil aircraft to act immediately on the clearance provided by ATC and a TCAS resolution advisory which conflicted with the resolution clearance provided by ATC.

This incident has been reviewed with the responsible controller and has been incorporated into training materials at the Center. Predictive thresholds for conflict detection are being adjusted. The conflicting TCAS resolution advisory represents a problem of long standing and cannot be remedied by action at this level.

Diagram of
the incident;
situation at
0017Z 04/26/97



Note: This document is not real - it has been created for research purposes only

ATC FREE FLIGHT INCIDENT REPORT	DATE: 04/26/97	PAGE <u>2</u> OF <u>3</u>
This form will be used to report incidents involving aircraft in free flight as defined in Handbook 1165.1. Reports will be completed within five days of occurrence and sent by fax to ATP-100. Appendices may be forwarded by ordinary mail.		
2. DETAILED DESCRIPTION OF INCIDENT		
<p>1. The incident occurred on airway J5 about 20 miles south of J80 at a time of heavy inbound traffic flow from the east toward San Francisco (KSFO) and Oakland (KOAK). The weather over Coaldale was scattered to broken cirrus cloud decks at multiple levels between FL 200 and 290; winds westerly at 70-75 kts. Light-moderate turbulence had been reported at all altitudes from FL 300-390 in the area. The incident was preceded by turbulence encounters by nearly all aircraft traversing the sector above FL 290. AA337, northbound to PDX in free flight, declared a descent from FL 330 to 290; the other two northbound aircraft (Cessna N88Q, on J5, and UA964, in free flight enroute PDX) were at or climbing to FL 290. NW905, southbound in free flight, was descending to 310 because of moderate turbulence at higher altitudes.</p> <p>2. At 0006, Kiwi 175 experienced a transponder failure 30 mi. SW of OAL enroute MOD descending from FL 290. This failure was not noticed for approximately 2 minutes. At 0010:30, voice transmissions were blocked for 1:30 by an apparent stuck microphone on VHF.</p> <p>3. At 0014, the controller recognized that a potential problem existed reference AA337, descending to FL 290 to avoid turbulence. He contacted AA337 and amended 337's clearance to maintain FL 310, but AA 337, already below that altitude, was slow to respond. The DART readout indicates that AA337 descended to FL 294 and was in momentary conflict with Cessna N88Q maintaining FL 290. N88Q was also recommended to descend to FL 280 but separation was lost between N88Q and UA964. UA964 was given a right turn by voice when the controller realized that 88Q and 964 were converging, but this transmission was blocked by UA964's call of N88Q as traffic in conflict. At 0015, the controller recognized a potential conflict of AA337 with NW905 and amended NW905's clearance to maintain FL 330.</p> <p>4. N88Q and UA964 received resolution advisories from their TCAS units, which directed N88Q to descend but directed a climb for UA964; the climb, which was not notified to ATC until it was completed at FL 300, brought UA964 briefly into conflict with AA337.</p> <p>5. The controller was busy handling the stream of inbounds to KSFO/KOAK and keeping them clear of the crossing aircraft in free flight. He indicated that he expected the crossing traffic to be well above the descent altitudes for aircraft crossing J5 and J7, as is usually the case in this area. Additionally, he was maintaining close surveillance of the automatic conflict detection and resolution software, which has just been placed in operation in this facility, and this added to his workload. Finally, the TCAS advisory to UA964 was not notified to ATC until after the aircraft had leveled at or close to FL 300 after climbing on a converging course with AA337 and this momentarily posed yet another problem for the controller, who had to evaluate another potential conflict before the others had been fully resolved.</p>		

Note: This document is not real - it has been created for research purposes only

ATC FREE FLIGHT INCIDENT REPORT	DATE: 04/26/97	PAGE <u>3</u> OF <u>3</u>
This form will be used to report incidents involving aircraft in free flight as defined in Handbook 1165.1. Reports will be completed within five days of occurrence and sent by fax to ATP-100. Appendices may be forwarded by ordinary mail.		
3. ANALYSIS, FINDINGS, RECOMMENDATIONS ANALYSIS: <p>DART and data link readouts were prepared after the incident. The above summary was prepared from the tapes on 04/29/97. During interviews, the controller indicated that he lost the picture of his north-south crossing traffic momentarily because of the large number of altitude changes being undertaken by these and other aircraft; he was unable to reestablish a clear picture because not all of the flight data had been updated. In particular, AA337's altitude revision did not appear on that aircraft's flight data screen until after the incidents, probably because of late processing of a data link message.</p> <p>FINDINGS:</p> <p>Conflict alert software functioned correctly, but did not provide enough advance notice to the controller of the conflict between AA337 and N88Q to resolve the problem without loss of separation. Point of closest approach between these two aircraft was approximately 0 ft and 2-1/2 miles. Also, AA337 was slow to respond to its resolution clearance and UA964's crew said they did not have time to acknowledge their TCAS advisory until they had responded with a climb. Complexity in the sector was moderate prior to the incident, in large part because of the north-south free flight and controlled aircraft, which were either requesting or executing descents or altitude amendments to avoid the turbulence above FL 290.</p> <p>There is an unresolved problem in areas containing a mix of free flight aircraft and aircraft under positive control. This mix is characteristic of this and some other sectors under control of this facility. Under some conditions, it becomes necessary to segregate controlled from uncontrolled aircraft, yet this cannot be done without imposing restrictions on aircraft in free flight, which conflicts with policy guidance concerning free flight. The alternative is to require that aircraft inbound to a terminal area be descended earlier, to keep them below the paths of overflying enroute traffic, and this also conflicts with the principles of free flight. Until this problem can be resolved, however, incidents like these will continue to occur unless controllers assume a greater degree of control over the enroute traffic.</p> <p>RECOMMENDATIONS:</p> <p>It is recommended that until new policies and/or technologies to avoid this sort of situation can be worked out, unrestricted flight under the free flight program end at some point prior to the primary inbound fix serving a terminal area, so that controllers can establish more orderly traffic flow prior to having to accommodate the streams of crossing traffic. Attempting to do this diverted attention from the separation task and increased the sector controller's workload at a time when he was already planning for the handling of a substantial number of aircraft while trying to accommodate north- and southbound aircraft transiting the sector.</p> <p>Unexpected concentrations of traffic such as occurred in this case can occur without warning. Procedures to invoke positive control in place of free flight need to be able to be invoked rapidly to permit orderly handling of such situations.</p>		
4. TYPED NAME OF PREPARING OFFICIAL Oliver S. Ulrich, Supervising Controller	FACILITY ZOA-112	DATE 05/01/97

FORM 1935c (Approved OMB 00002 6/96)

Ohio State University Cognitive Systems Engineering Laboratory 01/19.

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ATC FREE FLIGHT INCIDENT REPORT

DATE: 11/11/97

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This form will be used to report incidents involving aircraft in free flight as defined in Handbook 1165.1. Reports will be completed within five days of occurrence and sent by fax to ATP-100. Appendices may be forwarded by ordinary mail.

1. SUMMARY (Include graphics as necessary)

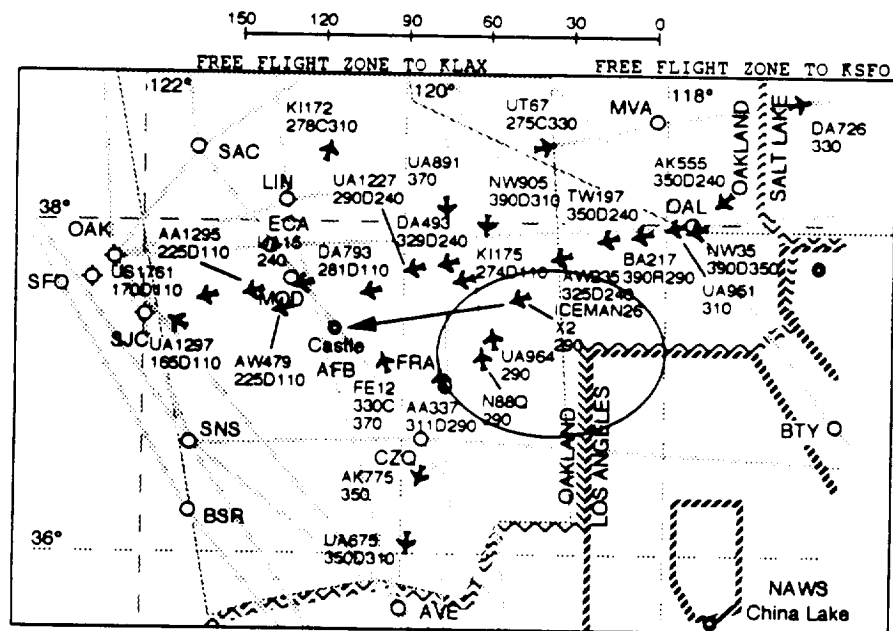
SUMMARY: At approximately 0017Z (1617 PST) on Friday, November 11, 1997, an incident occurred on airway J5 20 mi. south of J80. The incident involved two Air Force aircraft, a KC-135 tanker and a C-141 receiver, proceeding as a flight of two toward Castle AFB on a priority clearance. The tanker-receiver flight was in conflict with two civil transport aircraft northbound on direct routes under the control of Oakland Center, which was also controlling the Air Force aircraft. The two civil aircraft also were involved in an operational error at about the same time.

Conflict detection and resolution programs detected the conflicts and provided resolution advisories which were forwarded to the transports by the responsible controller. One advisory was too late to prevent an incursion into the refueling block; one was not acted upon in timely fashion by the flight crew.

This incident was caused by a combination of circumstances: the conflict detection system did not predict one conflict soon enough to provide a timely resolution advisory; the controller, who was heavily loaded at the time, foresaw the potential conflict between the two civil aircraft too late to provide a timely diversion. Contributing factors were the failure of the flight crew of one civil aircraft to act immediately on the clearance provided by ATC and a TCAS resolution advisory which conflicted with the resolution clearance provided by ATC.

This incident has been reviewed with the responsible controller and has been incorporated into training materials at the Center. Predictive thresholds for conflict detection are being adjusted. The conflicting TCAS resolution advisory represents a problem of long standing and cannot be remedied by action at this level.

Diagram of
the incident;
situation at
0017Z 11/11/97



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ATC FREE FLIGHT INCIDENT REPORT	DATE: 11/11/97	PAGE <u>2</u> OF <u>3</u>
This form will be used to report incidents involving aircraft in free flight as defined in Handbook 1165.1. Reports will be completed within five days of occurrence and sent by fax to ATP-100. Appendices may be forwarded by ordinary mail.		
2 DETAILED DESCRIPTION OF INCIDENT <p>DETAILS OF THE INCIDENT: The incident occurred on airway J5 about 20 miles south of J80 at a time of heavy inbound traffic flow from the east toward KSFO and KOAK. At 2400, ZOA received a request for a priority clearance for ICEMAN 26, a KC-135 tanker aircraft which had been refueling ASPEN 15, an SR-71 within Edwards AFB airspace, for an emergency refueling on an east-west track crossing OAL between FL 250 and FL 300. The refueling involved a C-141, SAFEGUARD 36, enroute to Kirtland AFB carrying hazardous cargo, which had experienced an engine failure and had hydraulic system problems.</p> <p>The weather over Coaldale was scattered cirrus cloud decks at various levels between FL 200 and 280; winds westerly at 70-75 kts. Light-moderate turbulence had been reported at all altitudes from FL 300-390 in the area.</p> <p>The clearance was issued at 0001 and the tanker departed the Edwards range northbound. All aircraft with data link capability were immediately notified that the Free Flight Zonal Boundary was shifted 100 miles to the east of OAL. The same message was broadcast on voice channels and ZLC was asked to notify non-data link aircraft still in its airspace of the change. Center tapes indicate that this message was acknowledged by most, but not all, aircraft affected by the change.</p> <p>At 0004, the tanker reported radar contact with its receiver from a position 15 west of OAL and commenced a right turn to 040. At 0007, ZLC handed off the C-141 40 NE of OAL proceeding southbound. Shortly thereafter, the tanker reported visual contact with the C-141 and commenced a right turn toward a heading of 235° direct Castle. The C-141 followed and joined at 0010 at FL 290. Refueling commenced immediately.</p> <p>At 0006, Kiwi 175 experienced a transponder failure 30 mi. SW of OAL enroute MOD passing FL 270. This failure was not noticed for approximately 2 minutes. At 0010, the watch supervisor at ZOA recognized that traffic in the affected sector was becoming heavy and assigned an assistant to the sector. At 0010:30, voice transmissions were blocked for 1:30 by an apparent stuck microphone on VHF.</p> <p>The operation was made more complex by a number of north- and southbound aircraft in free flight to and from the Los Angeles area, some of which were descending to FL 280/290 to avoid turbulence at higher altitudes. Among these aircraft were AA337, Cessna N88Q and UA 964. AA337 was descending to FL 290; N88Q and UA 964 were maintaining FL 290 because of turbulence. Southbound NW905 was also descending to 310.</p> <p>The conflict detection module recognized potential conflicts and recommended that AA337 climb to FL 310; this clearance was transmitted on data link, but the aircraft was slow to comply and crossed over the military aircraft about 800 feet above and a half mile ahead of them. N88Q was recommended to descend to FL 280 but separation was lost between N88Q and the tanker-receiver pair before the data link clearance was acknowledged. N88Q and UA964 also experienced TCAS resolution advisories. UA964 was given a right turn and immediate climb by voice when the controller realized that 88Q and 964 were converging, but entered the refueling block at FL 294 about 1 mile east of the military aircraft and two miles east of N88Q. The tanker maintained its course and altitude because the receiver was experiencing intermittent difficulty maintaining directional control; the tanker called AA337 and N88Q as traffic but did not observe the United aircraft. It reported refueling complete at 0019 and began an immediate descent toward Castle AFB with the receiver following.</p>		

FORM 1935b (Approved OMB 09602 6/96)

Ohio State University Cognitive Systems Engineering Laboratory 01/19/98

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ATC FREE FLIGHT INCIDENT REPORT	DATE: 11/11/97	PAGE <u>3</u> OF <u>3</u>
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<p>3. ANALYSIS, FINDINGS, RECOMMENDATIONS</p> <p>ANALYSIS:</p> <p>DART and data link readouts were prepared after the incident. The above summary was prepared from the tapes on 11/15/97. During interviews, the lead controller indicated that he lost the picture of his north-south crossing traffic for a short time because of the large number of altitude changes being undertaken by these aircraft; he was unable to reestablish a clear picture because not all of the flight data had been updated. In particular, AA337's altitude revision did not appear on the flight data screen, probably because of late processing of a data link message.</p> <p>The conflict resolution software functioned correctly, but did not provide enough advance notice to the controllers of the conflict between N88Q and UA894 to resolve the problem without loss of separation. Point of closest approach between these two aircraft was approximately 0 ft and 2-1/2 miles. Also, AA337 was slow to respond to its resolution clearance and N88Q did not have time to acknowledge its amended clearance via data link, though it did acknowledge by voice.</p> <p>Complexity in the sector was high prior to the incident, in large part because of the north-south free flight aircraft and the refueling path taken by the tanker because of its receiver's control difficulties. These aircraft were on UHF, which was not blocked by the stuck microphone on the VHF channel, but it was not immediately clear which channel was obstructed and the controller was concerned about KI175's altitude reference the refueling block.</p> <p>RECOMMENDATIONS:</p> <p>Because of the high likelihood of "bunching" at points on the periphery of the Free Flight zone, it is recommended that Free Flight end at some point prior to the primary inbound fix serving a terminal area, so that controllers can establish more orderly traffic flow prior to having to merge the streams of inbound and crossing traffic. The zonal boundary was moved during this incident, but doing so diverted attention from the separation task and increased the sector controller's workload at a time when he was already handling a substantial number of aircraft and planning for the effect of the refueling on or near J-80.</p> <p>Though free flight is now accepted policy, it should be noted that when numerous aircraft submit altitude or course changes nearly simultaneously, it can be difficult for controllers to adjust their crossing traffic flows to take account of the new aircraft trajectories. This was also noted in the earlier expanded NRP program when a sector contained both enroute (NRP) traffic and traffic transitioning to a terminal area. The situation that occurred here is not specifically cited in current procedures.</p> <p>Unexpected concentrations of traffic such as occurred in this case can occur without warning. Procedures to invoke positive control in place of free flight need to be able to be invoked rapidly to permit orderly handling of such situations. This poses a particular problem close to the boundaries of a Center's airspace (the ZLC boundary lay within the area in which the tanker and receiver joined up).</p>		
4. TYPED NAME OF PREPARING OFFICIAL Oliver S. Ulrich, Supervising Controller	FACILITY ZOA-112	DATE 11/15/97

FORM 1935c (Approved OMB 09602 8/98)

Ohio State University Cognitive Systems Engineering Laboratory 01/19/96

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U.S. Department
of Transportation
Federal Aviation
Administration

Advisory Circular

Subject: OBSTACLE-BASED CONTROL IN FREEFLIGHT AIRSPACE Date: 2/11/97 AC no: 81-85C
Initiated by AFS-840

1. **PURPOSE.** This advisory circular (AC) provides guidance for pilots on operating procedures in and around obstacles in free flight airspace, as contained in Federal Aviation Regulations (FAR) part 141.

2. **CANCELLATION.** AC 90-91, Operating procedures: National Route Program, dated August 6, 1992 is cancelled and superseded by this advisory circular AC81-85C.

3. **OTHER DOCUMENTATION.** Free flight principles are discussed in the 1995 final report of RTCA Task Force 3.

4. **THE CONCEPTS.** When free flight cannot be maintained because local problems have arisen that demand positive air traffic control, it is important that controllers set aside the MINIMUM safe amount of positive control airspace in order to maintain efficient traffic flow.

a. *Obstacle-based control* allows controllers to set aside parts of their sector for positive control, and free flight traffic can be asked to divert around these obstacle areas - to continue unhampered as long as it stays clear from the resectored area. In other words: traffic within an obstacle area where a problem has arisen is under positive control. It will receive radar vectors and altitude clearances, whereas traffic outside the obstacle area is still in free flight and can merely be asked to stay outside.

b. *The need for obstacle areas* in free flight airspace may arise during local problems (such as severe concatenations of traffic, or an emergency of one aircraft) that demand clearance-based control. Where this is the case, an obstacle area can be declared by the controller.

Aircraft within the obstacle area will be required to submit to positive control and comply with controller clearances. This allows the controller to actively solve the problem in the local area, while creating minimum interference with free flight traffic around the obstacle area.

5. **COMMUNICATIONS.** This section explains the communications in obstacle-based control, as set forth in FAR part 141 and the Aeronautical Information Manual 1997.

a. *Controllers* can be expected to broadcast to aircraft within their sector the geographical and altitude boundaries of the area that will be, or just has been, declared positive control obstacle area. Controllers can use both latitude/longitude information or make reference to VOR-DME beacons or airports. For instance, a broadcast message may sound: "area from OAL VOR to 50 nm west of OAL stretching 10nm north and 10nm south of OAL between FL200 and FL330 is now under positive control." It will shortly be possible to digitally uplink the geographical area with altitude information, onto navigation displays of rightly equipped aircraft. Within the obstacle area, pilot-controller communications proceed as normal under clearance-based control (see AIM 1997).

b. *Pilots* do not need to verbally acknowledge the obstacle broadcast and are free to circumvent obstacle areas. If pilots wish to enter the obstacle airspace, they need to ask for an ATC clearance to do so - as is the case with entry into any non-free flight airspace today. Unauthorized entry into positive controlled obstacle airspace is prohibited under FAR 141. Once within obstacle airspace, pilots are under positive control and may not deviate from altitude, heading, or airspeed clearances without controller permission.

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Section 1. OBSTACLE-BASED CONTROL

5--59 FREE FLIGHT CONCEPT

Free flight can provide the needed flexibility and capacity for the foreseeable future. It enables user-preferred flight paths that can be dynamically adjusted: the pilot is able to operate the flight without specific route, speed, or altitude clearances. Restricting the flexibility of the pilot will only be necessary when:

- 1) potential maneuvers may interfere with other aircraft operations;
- 2) traffic density in congested airspace precludes free flight operations;
- 3) unauthorized entry into special use airspace is imminent;
- 4) safety of flight restrictions are considered necessary.

5--60 APPLICATION

In case of any of the conditions under Par 5--59 sub 1)-4), controllers should resist revoking free flight within entire sectors. They should do this only when it is absolutely necessary. The above four conditions happen often in local areas, rather than across an entire sector. Therefore, to adequately deal with a problem, free flight can often be revoked only in local areas, rather than in an entire sector.

When free flight cannot be maintained because local problems arise that demand positive control, it is important that controllers set aside the minimum safe amount of airspace to deal with the problem. Within the portion that is set aside, controllers will manage aircraft under positive control. Other free flight traffic that is not going to be part of the problem can be requested to divert around the portion. This will facilitate safe, orderly and continuously efficient flow of traffic in free flight airspace.

5--61 TERMS

a. *obstacle* -- the area, or volume, of positively controlled airspace set aside by the controller. Within the obstacle, air traffic can be given heading, speed, or altitude clearances, or other kinds of information or directives that help the controller deal with the local problem. The portion set aside is called an obstacle, because that is what it creates for free flight traffic: an obstacle that they must circumvent in ways that are as economical as possible for them.

b. *obstacle-based control* -- the procedure of setting aside a portion of airspace to deal with local problems and having free flight traffic divert around it.

c. *affected air craft* -- the aircraft that are going to be in the obstacle and under positive control.

d. *non-affected air craft* -- the aircraft that are not in the obstacle, but still in free flight somewhere around the obstacle.

5--62 OBSTACLE METHODS

When free flight must be revoked locally to deal with any of the conditions under Par 5--59 sub 1)-4), use the following method:

a. Inform the affected aircraft that they are of free flight and proceed to give them the clearances or other information or directives necessary to solve the problem.

Phraseology:

(identification) YOU ARE NOW OFF FREE FLIGHT
TURN HEADING/ DESCEND/ CLIMB/ SLOW TO
(give clearance)

b. Broadcast to the non-affected aircraft where the obstacle is that they should circumvent. A controller can do this by reference to latitude/longitude information or by reference to VOR-DME and/or airports. In some cases other landmarks or airspace characteristics can be used as well, such as borders of military or special use airspace. The altitude range of the obstacle should also be made specific by reference to flight levels or thousands of feet.

Phraseology:

FREE FLIGHT TRAFFIC IN SECTOR (identify sector) THERE IS AN OBSTACLE FROM (give lateral boundaries), RANGING FROM (give altitude boundaries).

Note: NO acknowledgement from free flight traffic about the broadcast is necessary; it should therefore not be awaited or expected by the controller.

c. If the controller is uncertain about reaching all free flight traffic, he can request specific aircraft within this traffic to relay the broadcast.

d. If an aircraft in free flight is inadvertently about to enter the obstacle, this situation is similar to the one under Par 5--59 sub 3). The controller can take this aircraft off free flight using the method under Par 5-62 sub a).

Note: Non-affected traffic is not allowed to enter the obstacle without a clearance from the controller.

e. If a non-affected aircraft wishes to negotiate about entry into the obstacle, the controller can accept this traffic, workload permitting.

5--62a Reference -- FAR part 141: Aeronautical Information Manual 1997.

Para 5--59

11-11-3

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<p>1. SUMMARY (Include graphics as necessary)</p> <p>SUMMARY: At approximately 1915Z (1115 PST) on July 6, 1998, an incident occurred 5nm east of Coaldale, near the Free Flight zonal boundary for east inbound traffic to San Francisco. The incident involved two civil transport aircraft inbound to KSFO under free flight rules.</p> <p>One of the aircraft, inbound from DEN, initiated a right 360 degree turn before reaching Coaldale VOR (OAL) to let crossing North-South free flight traffic west of OAL pass in front of him. The right turn brought this aircraft in conflict with another civil transport inbound on a great circle route from PIT. The latter aircraft, descending in order to be over OAL at FL240, reacted too late to the T/CAS resolution advisory, and safe separation could not be maintained.</p> <p>Since both aircraft were under free flight rules, the controller was not actively involved in separation. Controlling traffic closer inbound to OAK, SFO and SJC had his first priority.</p> <p>The incident was caused by a self-initiated 360 turn of one of the aircraft and a late reaction to an RA of the other aircraft. The fact that ATC cannot actively monitor all of the free flight traffic, let alone predict their movements, is thought to be a contributing factor.</p> <p>The recommendation that the free flight boundary be extended 50 miles to the east of OAL was not acted upon after free flight incident 11/11/97. The latest incident indicates once more the clear need for active control east of Coaldale.</p>		

FORM 1935a (Approved OMB 09602 6/96)

Ohio State University Cognitive Systems Engineering Laboratory 01/19/98

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2. DETAILED DESCRIPTION OF INCIDENT <p>DETAILS OF THE INCIDENT: The incident occurred mid-morning, at a time of light to moderate inbound free flight traffic flow from the east toward San Francisco. Due to a coastal winter front, the weather was IMC from FL 290 down to approximately 500ft.</p> <p>At 1902Z, a B737, inbound from PIT on a great circle route in free flight announced to Oakland Center it estimated to cross inbound fix (OAL) at 1917Z and requested FL240 crossing OAL with subsequent straight-in for SFO. FL240 for crossing OAL was approved, as was direct OAL to SFO.</p> <p>At 1905Z another inbound aircraft, an A320 from DEN, reported 20 miles east of OAL, and asked Oakland Center to get a traffic advisory about crossing north-south freeflight traffic that was flying west of OAL.</p> <p>Oakland Center reported incoming waves of crossing free flight traffic: one to the north, and one to the south of the A320's projected track beyond OAL. Most of this traffic would have cleared the area in 5 to 10 minutes. The A320 asked whether it could hold briefly east of OAL at FL240, and go through the area of crossing traffic later. The responsible Oakland Center controller told the A320 he was welcome to do so, but advised the A320 of traffic at four-o'clock high. This was the B737 inbound from PIT. Both aircraft were in free flight, so Oakland center took neither the A320, nor the B737 under positive control.</p> <p>Due to a number of missed approaches in IMC at SFO and OAK between 1906z and 1915Z, the Oakland Center controller became preoccupied at that time: he had to coordinate with SFO and OAK approach control in order to re-vector his aircraft around SFO and OAK. Priority was given to this positive controlled inbound traffic west of OAL. The A320 crew reported that they attempted unsuccessfully to contact Oakland Center between 1910Z and 1914Z in order to confirm the feasibility of a temporary hold east of OAL.</p> <p>At 1906Z, the B737 had started a descent (in free flight) in order to be over OAL at FL240.</p> <p>At 1914Z the A320 initiated a 360 degree rate 1 right turn. Turning right was its only option, given restricted Edwards Ranges to the South. This turn brought the A320 in direct conflict with the oncoming B737. The B737 did not act quickly enough to its resolution advisory (which asked the B737 to climb) and separation was lost between 1915Z and 1916Z. The A320 responded to its RA by descending, but also aborted its turn, now flying outbound from OAL on a northeasterly heading and passing in front of the B737 from left to right at an estimated distance of 2 miles.</p> <p>At this time the Oakland Center controller had been alerted by conflict detection software. He declared the area just east of OAL positive control so he could vector the aircraft across OAL. The B737 received permission to cross over OAL at FL240, and the A320 was asked to continue the right turn and was brought in behind the B737, also at FL240. Most of the crossing traffic had cleared the area just west of OAL by then, and no further conflicts or RA's occurred.</p>		

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<p>3. ANALYSIS, FINDINGS, RECOMMENDATIONS</p> <p>ANALYSIS: A DART readout was prepared after the incident. Tapes were sequestered. A transcript of the intra-cockpit communications of both the A320 and B737 as well as applicable Oakland Center communications are attached to this report.</p> <p>By asking Oakland Center for a traffic advisory and the option to hold, a climate was created in which it had become unclear exactly what kind of control the A320 was under. Although technically still under free flight rules, the A320 had put itself in a position where it wanted confirmation from ATC about the 360 turn it was about to make. Whether the pilot intended to ask permission is unclear, and at any rate, this would not have been necessary since the aircraft was not under positive control.</p> <p>The responsible Oakland Center controller could have anticipated that a problem might develop after the A320 asked for traffic information. The controller knew that other traffic was in the area and that a potential problem between the freely turning A320 and other traffic could develop. It would have helped the A320 in his judgment of whether to turn or not if the controller had told him that the B737 was not just traffic 4-o'clock high, but actually inbound for the same fix.</p> <p>Under free flight legislation - that is in favor of efficiency - controllers are encouraged to take active control only when safety is clearly at stake. The responsible Oakland Center controller judged that this was not yet the case, given the light traffic load east of OAL.</p> <p>RECOMMENDATIONS: It is believed that permanent positive control east of OAL will prevent these situations in the future. Once more, it has become clear that active involvement of Oakland Center in the funneling of aircraft east of OAL is safe and necessary.</p> <p>Crossing traffic that is flying in free flight remains an issue of some gravity. It seems backwards from an efficiency standpoint that incoming traffic (needing to keep their slot times etc.) should have to wait for traffic that is in cruise. In addition, the weaving of controlled traffic through free flight traffic is not without hazards.</p> <p>ATTACHMENTS:</p> <ol style="list-style-type: none"> 1. transcript of intra-cockpit communications of A320 and B737; 2. transcript of ATC communications; 3. relevant NASA ASRS Callback. 			
4. TYPED NAME OF PREPARING OFFICIAL		FACILITY	DATE
Curt S.E. Langendorf, Supervising Controller		ZOA-112	01/30/98

FORM 1935c (Approved OMB 09602 6/96)

Ohio State University Cognitive Systems Engineering Laboratory 01/19.

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APPENDIX

COCKPIT VOICE RECORDER TRANSCRIPTS

Respectively from:
AW 335 A 320
US 1114 B 737

LEGEND

RDO	Radio transmission from incident aircraft
CAM	Cockpit area microphone voice or sound source
-1	Voice identified as Pilot-in-Command
-2	Voice identified as Co-Pilot
OAK	Radio transmission from Oakland Center
OPS	Radio transmission from America West Operations Control (Dispatch)
*	Unintelligible word
#	Expletive
()	Editorial insertion
...	Pause

Note: all times are in UTC (Zulu time)

Albert G. Reitan
Transportation Safety Specialist (CVR)

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INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT
START OF TRANSCRIPT CA CTUS 335 A320			
1854 39 CAM-2	Man Mike seemed pretty adamant about this upset thing this morning	1900 29 RDO-2	Ops good morning this is three thirty five inbound SFO
1855 27 CAM-1	You can say that again. Guess it shook 'm up pretty bad. # passengers you can tell 'm a million times to wear their # belts. I can't help it if they still bang their # heads	1900 46 OPS	Well hello there three thirty five what can I do for you guys
1856 10 CAM-2	** ha ha ha	1901 03 RDO-2	Ops you got anything on crossing free flight traffic after Coaldale what we should do with it?
1858 19 CAM-1	Tell ya what. Let's ask dispatch what they know see what they'd want us to do if it's bad again after Coaldale	1901 27 OPS	Stand by I'll need to check.
1859 04 CAM-2	Swet.	1902 21 OPS	Yeah ah three thirty five ah I've found a memo here just got it this morning. Says that if ah there's much crossing traffic beyond Coaldale that's likely to cause lots of upsets then ah you might want to check with ATC and hold east of Coaldale so you can go through at a later time. Ah it says too that ah since we have no connections for this flight at SFO ah bla bla bla ah after what happened yesterday giving them a smooth ride in is more important than getting them there early right whatever that may mean
INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT
1904 23 CAM-1	Sounds like we want to call Oakland and see what they have	1903 28 RDO-2	OK ops thanks appreciate it
1904 37 CAM-2	Yeah you're right	1903 40 OPS	You're welcome guys good day
1906 27 CAM-1	Wow	1905 10 RDO-2	Oakland center Cactus three thirty five 80 miles east of Coaldale ah inbound SFO
1906 35 CAM-2	Pretty much means we'd have to hold for a little while huh	1905 19 OAK	Cactus three three five I gotcha. Keep on coming in
1906 39 CAM-1	Yeah let's ask 'm	1905 30 RDO-2	Ah oakland ah we'd like to have a final advisory is there much traffic to the north and south of us after we pass Coaldale uh correction much crossing traffic free flight crossing traffic that we'll have to go through?
		1905 58 OAK	Cactus standby
		1906 10 OAK	uh Cactus alternative you've got a big wave to the north of you and uh standby ah looks like there's a lot to the south as well we're gonna have to do a lot of weaving

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT
		1906 43 RDO-1	Oakland Cactus three three five we'd like to ah briefly hold east of Coaldale to let crossing traffic pass.
		1906 59 OAK	Roger sr ah three three five ah do as you want traffic 4-o'clock high just let me when you want to come in
		1907 20 RDO-1	Oakland ah we don't have trfct on the visual or TCAS. So ah were ah cleared for this hold ah wild on when we come in three thirty five
		1907 43 OAK	sr
1908 10 CAM-2	Well, that was easy		
1908 29 CAM-1	Yeah uh now we need to go do this hold to the right don't we? We've got Edwards or somethin' here to the south, right?		
1908 54 CAM-2	ah lemme check ah yeah that's right yeah Edwards. So gotta turn north. Now there's traffic at four-o'clock high so that's to the right behind us somewhere but it's high		
1909 15 CAM-1	north OK let's ask 'm one more time		
1909 22 CAM-2	good plan		
		1910 36 RDO-1	Oakland Cactus three thirty five we'd like to ah verify hold to north

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT
		1911 13 RDO-1	Oakland Center three thirty five?
1911 45 CAM-2	"Hmnn.		
1912 10 CAM-1	Let's keep tryin'		
		1912 33 RDO-1	Oakland Center Cactus three three five
1913 00 CAM-1	Not good... We gotta start doing something pretty soon here.		
		1913 31 RDO-1	Oakland Center Cactus three thirty five were turning north, ah holding east of Coaldale
1913 47 CAM-2	Where is the traffic now?		
1913 58 CAM-1	ah Let's turn.		
1914 18 CAM-5	traffic, traf fic (sound of TCAS advisory)		
1914 25 CAM-1	Where the f...?		
1914 37 CAM-5	descend, descend, descend (sound of TCAS advisory)		
		1915 18 OAK	Cactus three three five, you almost flew into a USAF seven three. Maintain altitude and fly heading zero five zero

END OF TRANSCRIPT

CALLBACK

ASRS

Number 224

February 1998

So, who's in control, anyway?



When aircraft in free flight ask and receive advisory information from ATC, and subsequently act on the basis of this information, is it fair that the crew expect further assistance from ATC in, for instance, separation? Or does the free flight adage of "see and avoid" still hold and is the crew "on its own", so to say? This was exactly the dilemma an air transport crew found itself in when it had asked a traffic advisory for free flight traffic crossing in front of it.

First, we hear the account of the captain of the puzzled airliner:

Routine flight from ABC; inbound from the east to XYZ. I was PIC. Prior to reaching inbound fix, we called ATC to ask advisory about North-South traffic crossing in front of us beyond the fix. Although we are supposed to see other traffic now and be our "own little air traffic controller" in free flight, the TCAS display has too small a range to provide a good overview of traffic anyway. ATC reported heavy waves of traffic to the north as well as south of our intended track from fix to XYZ. On the day before our flight, one of our airplanes flying the same route had experienced combination of turbulence and many RA's due to this crossing traffic. Upset of aircraft caused one passenger injury. We were called into chief pilot's office before ABC departure and was told to do whatever we could to avoid turbulence. We decided to wait for the waves of crossing traffic to pass before we would cross the fix, exit free flight and go into XYZ. ATC said that was fine; we could hold before fix if we wanted. However ATC also advised us of traffic at 4 o'clock high. We were not told whether this traffic was inbound for the same fix. Also, were in IMC, so could not get visual on the traffic. TCAS did not show traffic either since it was over our right shoulder somewhat when we tried to call ATC to clarify we could not get through; the channel was congested. The fix was quite near now we needed to act: to our south was KXX range, so we could only turn right. 5 miles before the fix I started the turn, unable to concure with ATC re. other traffic. About quarter into turn we got an RA telling us to descend. Impounded immediately and also aborted our turn. While flying outbound from fix in northeasterly direction, ATC finally came back on and told us we had just turned into the other traffic, which had descended to the fix. We must have come pretty close; the traffic symbol on our TCAS was suddenly very close to our aircraft.

We were vectored in over fix behind other traffic. By now most crossing traffic had cleared, so no RA's or delays getting into XYZ.

I don't blame controller for lack of help or vigilance, after all we were in free flight. But some revision of procedure of who exactly is in control after receiving and acting on an advisory seems very necessary to me.

Apparently the incident sparked enough concern everywhere, for we received a report from the other involved aircraft as well. This is the captain (PNF) reporting:

On a great circle route westbound, direct from EFG, mostly in free flight west of Mississippi. Reported estimated arrival time over inbound fix for destination ABC, and said we'd like to be over fix at FL240. They said okay. Started descent toward fix 30 miles out, still in free flight. As always, we were tight on fuel on this flight, even though we fly great circle routes now. Head office has decreed that we take off with less fuel to save weight. Result is that cannot afford any diversions along way so we were counting on straight in over fix. While nearing fix, we heard other aircraft ahead of us asking ATC if it's okay to hold before fix. Didn't seem to get a reply, so we thought we were safe. Kept on going. We were very surprised to suddenly receive an RA to climb (the last thing we wanted to do given our fuel situation); apparently, the other aircraft had begun to turn on a makeshift holding pattern east of fix and was now turning right into us. First officer and I were both not expecting this and not happy with it. Others were reacting to the RA and I guess we came close to the aircraft turning in front of us.

Confusion about who is in charge while an aircraft is acting upon an advisory under free flight can be potentially dangerous, as our reporters found out. Crossing free flight traffic remains a concern for those who have to weave through it to get to their destination. Somehow it does not seem very efficient after all that they have to pay the price, mostly to the benefit of the aircraft that are in cruise.

Note: This document is not real - it has been created for research purposes only

2.2.5 The Scenarios: Role Playing in Cognitive Walkthroughs

In the cognitive walkthroughs, incidents that might occur and problems that might arise in a future Air Traffic Management (ATM) system are used in a different way. In these cases participants are given the background and context of a scenario and the rules under which the ATM system is operating. They are presented with the onset of an event and are then asked to “play out” the scenario as it occurs. The role playing is supported by a gaming board that represents the aircraft in particular ATC sectors. The participants can manipulate the gaming board to play out how the situation could evolve given different contingencies, actions, and interventions. Multiple participants debate among themselves different strategies for handling the situation. The methods by which they jointly resolve the problem are the data of interest. (See report no. 5 in this volume for a discussion of the background and results of this study.)

2.2.6 Basis for Walkthrough Scenarios

Cognitive walkthroughs were carried out to examine how controllers would perform in a management by exception role. Each walkthrough presented a developing air traffic situation and included a set of probes to challenge the participants based on the gaming area described in section 2.2.2. The probes varied to focus on different cognitive demands that could arise for an air traffic manager operating in a kind of free flight environment such as detecting or anticipating exceptions and adapting type of control to resolve problems.

2.2.6.1 Walkthrough 1:

Goal: Investigates whether immediate aircraft history and flight plan is sufficient for a manager to follow aircraft intent and to anticipate trouble.

Brief description of the scenario: While an incoming stream of free flight traffic inbound for SFO is about to start crossing over OAL, an aircraft (AW235) enroute from Portland, OR to Phoenix, AZ is between FMG and OAL, cruising south-eastbound. This airplane is squawking code 7600 on its Mode A transponder.¹ It is headed orthogonally for the incoming stream over OAL. Maneuvering the incoming traffic out of the way is constrained because of restricted airspace over the Tonopah military ranges to the South.

Probes: Two sources of information about aircraft intent (velocity vector and flight plan) are isolated for use by the air traffic manager in this case. AW235 is unable to display or transmit intent in any other way.

¹ Squawking 7600 means that an aircraft has suffered a communications failure: if the squawk is transmitted on Mode A, then Mode C may also be inoperative. Other aircraft interrogating this aircraft's transponder may see this airplane represented on their collision avoidance display, but they will not know its altitude, and their TCAS will be unable to issue them resolution advisories as a result.

2.2.6.2 Walkthrough 2

Goal: To examine how air traffic managers can intervene (a redistribution of authority) to resolve a problem. In particular, the case looks at a strategy where managers take only a few aircraft under positive control while other traffic reroutes around, or receive clearances for entry into that portion of airspace. Three variants of this case were developed to instantiate different conditions which might challenge this strategy.

Method: a cognitive walkthrough of three problem-solving situations.

Brief description of the scenarios: In order to prepare for their roles and play by the same rules during the walkthroughs, controllers were given a 1997 future excerpt from their controller's handbook, while pilots were presented with a 1997 future Advisory Circular (see pp. 26-34). These documents explain the specific rules of the RTCA strategy of declaring a portion of airspace under positive control to deal with exceptions (based on material from the RTCA 1995b vision of free flight) and forcing other traffic to reroute around, or request permission to enter into, that portion of airspace.

- 1) In the first situation, incoming traffic bound for SFO is no longer required to cross over OAL to exit free flight airspace, so it is scattered over a broader front, approaching the free flight boundary. This boundary, however, is enveloped in thunderstorms building up over the Sierra Nevada.
- 2) Here, free flight traffic to and from LAX, crossing over the stream of controlled traffic into SFO, encounters severe clear air turbulence (CAT) and starts descending into the arrival stream.
- 3) Here an aircraft enroute from FMG and headed for OAL suffers communication and Mode C failures *after* announcing that it is going to go east of course in order to avoid thunderstorms building up over the Sierra Nevada.

Probes: Rules on how to declare a portion of airspace under positive control (and forcing reroutes around or clearances for entry into the portion) were disseminated to the participants.

In problem variant (2), free flight traffic did not have to cross over a particular waypoint (OAL) to exit free flight airspace; it could do so anywhere it pleased. Although imposing possible difficulties, this allowed a clearer funneling pattern to emerge in the case of thunderstorms.

The prerequisites for the intervention strategy (i.e. what is required to make it possible to declare a portion of airspace controlled and ask other traffic to reroute around or enter only with a clearance) were instantiated in terms of *time available to prepare* a portion of controlled airspace and notify all agents, and in terms of the

clarity of the delineation of that airspace. These characteristics were varied over the three problem-solving situations as follows:

- 1) Thunderstorms: some advance warning (of thunderstorms cropping up and traffic headed for the area), and relatively fixed dimensions. Traffic pattern can be recognized (because of funneling) and may be familiar in that particular sector;
- 2) Clear Air Turbulence: more advance warning (after the first few free flight aircraft have descended into the arrival stream, it becomes clear that this is a problem that will affect every free flight crossing aircraft) and of fixed dimensions. Traffic pattern of descents can be recognized and may be familiar to controller in that sector;
- 3) Communications failure: no advance warning (of the failure); undetermined and uncertain dimensions of portion of airspace (unknown where aircraft may go), and no recognition of a pattern possible.

In addition, the three cases differ in the type of traffic pattern they can produce. In variants 1 and 2, traffic patterns can emerge and be recognized. This is not so in the third variant.

2.3 Data Collection Sessions

<p>Session I</p> <p><i>Participants</i></p> <p>2 controllers 1 pilot 1 dispatcher</p> <p><i>Techniques</i></p> <p>Knowledge Elicitation Future Incident Reports</p>	<p>Session III</p> <p><i>Participants</i></p> <p>2 pilots 3 dispatchers</p> <p><i>Techniques</i></p> <p>Knowledge Elicitation Future Incident Reports</p>
<p>Session II</p> <p><i>Participants</i></p> <p>3 dispatchers 1 pilot</p> <p><i>Technique</i></p> <p>Knowledge Elicitation</p>	<p>Session IV</p> <p><i>Participants</i></p> <p>4 controllers 1 pilot</p> <p><i>Techniques</i></p> <p>Cognitive Walkthroughs Knowledge Elicitation</p>
<p>Followup Sessions</p> <p><i>Techniques</i></p> <p>Cognitive Walkthroughs Structured Interviews</p>	

Figure 5-4: Data Collection Sessions using Conceptual Walkthrough and Future Incident Techniques

We brought together different specialists with different perspectives within today's air traffic management system for four data collection sessions (see Figure 5-4). The specialists included pilots, controllers, dispatchers, and air traffic managers in different mixes for the various sessions. In each session we used one or more of the conceptual walkthrough techniques in presenting concrete scenarios to guide the participants' exploration of possible future ATM worlds. Each technique varies in the kind of procedure followed (elicitation, review of a future incident report, cognitive walkthrough of a future scenario). The four data collection sessions were followed up by discussions with other individual practitioners to clarify or expand on results from the group sessions.

The reports brought together in this volume represent the results from using these techniques in the different data collection sessions. Some of the reports are based on the results of using a single technique in a single session (e.g., Report no. 3 is based on the knowledge elicitation technique using the scenario probes described in section 2.2.1.2). Others are derived from integrating results gathered with a single method across sessions (e.g., Report no. 4 uses the future incident technique and focuses on results from one session, but parallel results were obtained in other sessions). Finally, other reports are concerned with themes based on data integrated across multiple techniques and sessions (e.g., Report no. 5 on management by exception, and Report no. 7 on communication and coordination).

HUMAN-CENTERED TECHNOLOGIES AND PROCEDURES FOR FUTURE AIR TRAFFIC MANAGEMENT

3. HUMAN FACTORS ISSUES IN THE DESIGN OF A MORE FLEXIBLE ATM ENVIRONMENT: KNOWLEDGE ELICITATION BASED ON THE EXPANDED NATIONAL ROUTE PROGRAM

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3.1 Introduction

This report describes the results of a knowledge acquisition session involving the supervisor for air traffic services and two dispatchers from a major airline. The purpose of the session was to use a scenario based on experiences with the expanded National Route Program (NRP) in order to elicit the knowledge and views of these practitioners regarding areas for improvement of the expanded NRP and for developing new Air Traffic Management (ATM) initiatives in the future.

The improvements discussed fall into six categories:

1. Changing procedures within the ATM system so that the airlines have more flexibility in making choices based on their business concerns;
2. Providing better feedback to guide decision-making;
2. Improving information exchange and decision support tools;
3. Providing better training to improve utilization of the National Airspace System (NAS);
4. Increasing system capacity;
5. Dealing with organizational bottlenecks;
6. Supporting shifts in workload resulting from new roles and responsibilities.

The report ends with a consideration of some of the issues that must be dealt with to ensure safety and effective overall use of system capacity, with an emphasis on the role of the ATM system as a "referee".

3.2 Methods

The goal of this knowledge acquisition session was to elicit knowledge and insights from airline AOC staff about current and future ATM system initiatives. In order to generate discussion, a number of scenarios were presented to the participants based on actual experiences with the initial implementation of the expanded NRP. These observations were based on previous research conducted by Smith, McCoy, Orasanu, et al. (1995). The rationale behind this choice of scenarios was that the expanded NRP represents the most significant attempt to date by the ATM system to provide the airlines with increased flexibility to make decisions about selecting routes for flights based on their business concerns. Consequently, experience with that program offers the potential to provide insights into the issues that need to be considered in making decisions about the design of the ATM system in the future.

3.2.1 Subjects

Three highly experienced air carrier dispatchers took part in a six-hour knowledge elicitation session. The session was guided and moderated by members of the research team.

3.2.2 Procedure

This data collection session was held in February of 1996. The format for the meeting was as follows:

- Allow participants to read the scenario prior to coming to the meeting;
- Ask participants to be prepared to identify other types of important incidents/observations that should be included in discussions. (The scenario as described below dealt primarily with observations from the first 6 months after initiation of the expanded NRP.)
- Run through the list of observations and for each ask:
 - Is this an example of a real concern or improvement?
 - How significant is this concern or improvement?
- Discuss additional incidents/observations that should be added to the list;
- Run through the list of observations a second time and for those that have been rated as most significant ask what can we learn from them to guide us in designing the future air traffic system.

Below, short scenarios are presented in the form of actual observations about system performance during the initial implementation of the expanded NRP.

3.2.3 Instructions to Subjects

The goal of the short observations or scenarios described below is to focus attention on preflight planning at the airlines, and on the implications of such planning for air traffic management and air traffic control. These scenarios will be used to begin to address the following questions:

1. What rules and procedures should be adopted to govern the behaviors of the airlines and the Air Traffic Management (ATM) system during preflight planning activities? How will these rules and procedures deal with current concerns? Will they create any potential new concerns?
2. What rules and procedures should be adopted to govern the behavior of air traffic (including DoD, general aviation and commercial aviation traffic) and the actions of air traffic managers while flights are enroute in order to allow them to deal with situations that may arise as a result of the rules governing preflight planning?
3. What roles and responsibilities should be assigned to different individuals at the airlines and within the ATM system? What training is necessary to ensure effective performance in these roles?
4. What services should the ATM system provide to the airlines?
5. What information should be exchanged between the ATM system and the airlines (both real-time and historical information)?
6. What technologies need to be developed to effectively support these roles and responsibilities?

3.3 Scenario Overview

(This scenario set is summarized in report no. 2 of this volume, pp 2-11-13.) These scenarios are based on the ATM system as it existed from January 9, 1995 to December 31, 1995. (During the discussion, additional observations will be added based on more recent experiences.) It should be noted that during that time period the ATM system was operating under a hybrid rule structure, with a number of advisory circulars and orders in effect, including FAA Advisory Circular 90-91 as well as the order for the expanded NRP.

The basic question raised by these scenarios is: What can we learn from experiences that arose during the initial implementation of the expanded NRP, in order to guide us in future decisions about the design and implementation of the ATM system? This includes future decisions regarding the roles and responsibilities of the various people and the technologies embedded in such a future system.

3.3.1 The Scenarios

The order for the expanded NRP took effect on January 9, 1995. This program was phased in at progressively lower altitudes over the following twelve months. Advisory Circular 90-91 had been in effect for several years at that point.

To produce this scenario, we have documented a number of issues and situations that arose during that time period (some represent improved system performance, while others represent new or continuing problems). These issues and situations are described below as a set of observations, supported by anecdotal information elicited from their sources.

Observation 1. Data from one major airline indicated that the increased flexibility in flight planning provided during the first three months under the expanded NRP allowed its dispatchers to file flight plans with the potential to improve fuel efficiency on average by about 2.5%.

Observation 2. TMO: "The MAR program and the NRP program have been beneficial in a way. They have shown us a lot of places where we might have been a little comfortable. I've seen a lot of places where they've cut away some of the fat out there. We've almost eliminated our miles-in-trail restrictions at Oakland Center, for example. But I think we've reached the level we can handle with the technology we have today."

Observation 3. The expanded NRP gave the airlines more flexibility and control in selecting the routes for certain flights. It did not provide the airlines with any increased flexibility as far as ground stops were concerned. An example illustrating this is the following:

On a particular day, the ATM system predicted that San Francisco would only be able to accommodate 50% of its normal arrival capacity in 3 hours (from 10-11 am) due to bad weather. Ground delays were therefore initiated for a number of flights at various airlines. The meteorologists for one such airline, however, believed that there was a significant chance that the weather at San Francisco would clear before 10 am. Given that internal forecast, and given that the flight could be diverted to Oakland if the weather didn't clear, the responsible dispatcher concluded that it would be preferable from a business perspective to launch a flight from DFW to SFO that was being held because of the ground delay program. The ATM System did not accommodate this request.

Observation 4. Because of a closed runway, the arrival rate into LaGuardia for the next 3 hours was restricted to 75% of the normal rate. ATCSCC put a ground stop program into effect, holding a number of flights at other airports

on the ground. Several affected airlines wanted to substitute some of their delayed flights for others that were still scheduled to leave on time, as these delayed flights were much more time-critical in terms of passenger loads and connecting flights. The ATM system had no easy mechanism to accommodate this desire.

Observation 5. Traffic from the west into the northwest cornerpost at Chicago was very heavy. Consequently, this traffic was being sequenced to ensure efficient landings at O'Hare. When one airline wanted to file a flight from Minneapolis to Chicago, rather than simply telling the airline that the flight would be delayed for 20 minutes on the ground, the ATM system gave it a choice: "You can take a 20 minute ground delay and then be assured that you can be sequenced into the flow at the northwest cornerpost, or you can take off now with a 20% chance of being fit into that sequencing and an 80% chance that you will be vectored to the northeast cornerpost instead." The airline decided for business reasons to go ahead and launch the flight.

Observation 6. The expanded NRP raised certain concerns at some (but not all) Centers. As an example, one challenge arising from the expanded NRP was that airlines sometimes wanted to cross their high altitude flights over departure and arrival routes. For instance, for certain flights over the top of O'Hare, Chicago Center had always preferred that the traffic be routed over Badger in order to avoid having enroute traffic cross the departure lanes. One airline, however, preferred (and was now been filing) these flights over Iowa City-Waterloo under the expanded NRP. Such flights criss-crossed through the departure lanes, creating a "very tricky, complex operation" for ATC. This raised an interesting question: Do you let 3 or 4 planes cross at the cost of slowing departures by about 20%? This tradeoff was particularly interesting because such flights were most often slowing departures from Chicago of flights by two other airlines.

In contrast, at Oakland Center such criss-crossing traffic through arrival lanes is being allowed, but not without significant concern: "We're seeing a funnel effect. Where it used to be we would have 2 streams down to the Los Angeles basin, now everybody aims for Avenal. This works ok a lot of the time, except when things go wrong. When they go wrong, you suddenly have a whole herd of airplanes pointed at one point and a last minute change such as the need for an increase in the miles-in-trail or an airplane taking a wrong clearance, or any number of things, can cause a serious problem because you have a real concentration of airplanes. Suddenly you have to pull the plug to deal with it, whereas before at most you had a miles-in-trail situation, you had a bit more leeway. Even when it's workable, it puts a burden on the controller because it's not something they do every day."

"If you just take those aircraft crossing Coaldale at 39,000 feet, they've got to cross Modesto at 24 and you've got airplanes southbound at 29, 33 and 37,

northbound at 31, 35. It's pretty much like a charge. It makes it real hard to thread that guy from 39 down to 24 and at the same time do all the things you have to be doing. If it was just one airplane to get through anybody could do it, but we're talking multiple airplanes, because it's the old push time and they're all coming at once. Twenty minutes later there may not be an airplane in the sector, but for those 20 minutes it gets wild and crazy. Not having them on the routes the way they used to be has caused a lot of heartburn for the controller. They're having trouble getting them down."

Another concern introduced by the expanded NRP was due to the instruction to give preference to NRP flights. As one TMO stated: "It gets cumbersome because the NRP program says you're not supposed to touch them. So we have to move 3 or 4 other airplanes to solve one problem. They [the Command Center] encourage you to move other traffic to leave the NRP traffic alone."

A fourth example that arose as a direct result of the expanded NRP at some airports, and also as a result of an increased numbers of direct flights, had to do with balancing of loads at cornerposts: "If we get a jetstream right out of the southwest part of the country, everyone rides it [into O'Hare]. 75 percent of these airplanes are all coming in at the southwest cornerpost, creating a major volume saturation point. The old solution was to create a delay program to avoid launching too many flights into traffic, for example creating 20 minute delays at an airport, and to increase capacity by moving half a dozen flights to the northwest cornerpost. Under the expanded NRP, controllers were not allowed to use the latter solution. Controllers had no way of policing those flights, because if it said NRP it meant they were not supposed to reroute them. They were supposed to leave them alone."

A similar situation arose as a result of flights filed by a single airline which "had 5 flights which originated in the LA Basin, PHX and LAS. When they were all filed to the Southwest cornerpost at DTW during certain arrival banks, the result was an overload at that fix. We responded by moving a couple of those flights, or other flights originating in Florida, to another fix. It would have been cheaper for that airline to file some of them to that other fix to begin with."

A sixth example of an issue associated with the expanded NRP concerned what was happening when there were arrival rate restrictions (due to weather, etc.). For instance, in one case Kennedy had set a reduced arrival rate of 50 percent at 2 p.m. because of the weather forecast. To deal with this, Chicago Center began limiting flights bound for Kennedy that were flying the standard preferred routes. In addition, however, there were flights filed under the expanded NRP that were not limited. The net result was that the capacity for Kennedy was exceeded, with many planes "winding up in high altitude airborne holding, and that's a major problem."

Finally, holding itself has become more difficult: "If they do go into holding, you might not have these airplanes anywhere near the fix you have to hold them at. You have to pull them in from all corners of the sector, where before they'd all automatically be going over this point and all you had to do was issue a clearance and watch for the altitude. Now you've got to transition people all the way from the north and south to a common point and probably start doing a lot of altitude juggling at the same time."

Observation 7. At certain Enroute Centers such as Chicago and Cleveland, numerous examples were noted where new problems with air traffic congestion arose. It is important to note, however, that many of these concerns did not arise because of the preflight plans filed under the expanded NRP. As one TMO reported: The source of the major concerns was not the expanded NRP per se; it was the spin-offs of the expanded NRP, such as the increase in direct routes that were filed while flights were enroute. The impact was that flights were now going direct through sectors where they had not done so in the past. The major change in air traffic patterns wasn't due to flights filed under the new expanded NRP itself, as fewer than 5% of the flights were being filed under the new expanded NRP. It was due to this spin-off of the expanded NRP.

Specifically, once airborne, pilots were requesting and getting clearances for direct routes from controllers, who were clearing them on these direct routes without any approval from the affected sectors. This was apparently interpreted by these controllers as the "Free Flight" concept. (The actual order for the expanded NRP contained no such instructions.) The result for Chicago Center, for example, was that they were inundated with direct routes on the south side of the Center, in sectors that in the past had not been impacted by such traffic levels.

There was also a problem with the unpredictability of traffic loads from day to day. As an example, the flights to Newark were now coming through Chicago on various routes, often through different sectors on different days, depending on the winds. As a result: "One day a controller is inundated, the next day he's twiddling his thumbs." As one TMO put it: "The whole concept of traffic management is we don't shotgun any one controller. The guy who is working the initial point of the arrival, like Little Rock going to Blue Ridge arrival, we're now pointing a shotgun at his head and saying: 'Here come the airplanes'. Before, we had a structured flow into those fixes. Each time we melded 2 or 3 lines, a different controller was doing it, so finally we got down to one line. Our big fear now is a possibility in Memphis of a single controller having 3 of those points in a sector, so we're shotgunning him 3 times."

In terms of the magnitude of this problem, 70 to 80% of the flights over many Centers were now on direct routes. For some Centers, such as Kansas City

and west, this wasn't a major problem. For others like Chicago and east, there was a significant impact. Some aircraft had to be held at the Chicago Center, Cleveland Center, and Indianapolis Center boundaries because sequencing the resultant multiple flows became nearly impossible.

Observation 8. Another potential challenge was a concern with commuter flights. With aircraft like the Challenger jets, "they want to go to 37,000 feet." How will this traffic be handled if they start to take advantage of the expanded NRP?

Observation 9. As indicated above, pilots as well as controllers contributed to this sudden increase in direct flights. Pilots (with the permission of controllers) chose to fly direct instead of flying the route selected as "optimal" during preflight planning.

Below are two examples of this:

A dispatcher was riding jumpseat on a 757 flight from EWR to LAX which had been filed under the NRP by the dispatch staff. ATC offered the flight direct from EWC to PWE (south of the user preferred trajectory as determined during preflight by the dispatch staff). The Captain looked at the dispatch-provided data, which showed that this direct route would cost additional time and fuel. Nevertheless, because the FMS gave different data than the ground computer, the pilot chose to accept the offer of a direct route. The result was added time (4 minutes) and fuel burn (500 lbs.). (In order to make up the time they were losing 2 hours later, the flight changed its flight level and cruise schedule, which increased its overburn.) The flight also went through a convective sigmet with tops to FL 450 that they would pass to the north on the original route.

Another example was a flight that flew from DFW direct to Parker. The responsible dispatcher commented: "If a direct route had been better, I would have filed it through the NRP. I had planned it over Albuquerque because of a favorable southerly jetstream. Flying direct to Parker, the flight was flying directly into the jetstream. The plane was 6 minutes late."

A contributing factor in examples like the second one above appeared to be a lack of awareness by pilots as to when they were on an NRP flight plan. Interviews with pilots from several airlines indicated that they did not know when they were flying a flight plan filed under the expanded NRP.

Another example was even more extreme. As noted above, a by-product of the expanded NRP was a sizable increase in the number of direct flights approved while enroute. One of the pilots interviewed from a major air carrier indicated that he thought "that was what the expanded NRP was all about", that when a controller now offered him a direct flight, ATC and the

AOC had jointly determined that a direct flight was best for him in terms of weather and air traffic. His comment was: "I was tremendously impressed that they could achieve such coordination." (The reality was that such offers for direct flights were completely uncoordinated— the controllers weren't even checking with the other affected Centers, let alone the airlines, regarding the impact of such direct flights.)

Observation 10. A Dispatcher had a choice between filing a flight from LAX to DFW either north or south of White Sands. The northern deviation offered the shorter wind route. While enroute, however, the flight was rerouted to the southwest cornerpost because of traffic congestion. As a result, the flight burned substantially more fuel and was later than it would have been if it had originally filed the southern route to the southwest cornerpost.

Observation 11. A number of airline dispatchers and ATC coordinators were completely unaware of the dramatic increase in direct flights that occurred following the implementation of the expanded NRP (even though flights from their own airlines were involved).

Observation 12. The system for requesting non-pref routes through ATCSCC under the old NRP (Advisory Circular 90-91) provided an example of how procedures can be established to encourage the distribution of knowledge to relevant participants in the flight planning process. As one airline ATC coordinator stated: "When we started this [the procedure for requesting non-pref routes], even Central Flow didn't know where all the choke points were. But as we pressed the system and said 'now we want to fly over here', we'd call the Albuquerque Center and they'd say: 'You can't go eastbound over St. John at 4 o'clock in the afternoon.' Well, that was tribal knowledge in the Albuquerque Center. The tribe expanded to include Central Flow; Central Flow expanded the knowledge to the airlines and we [the airlines] began to build better routes. So rather than having to fly a 2000 mile route because it didn't work at one point, we began juggling around and making routes that were smarter. ... Originally, we'd call and they'd say no. But then it became: 'Well, if you would just do this, if you'd just make this minor adjustment in your flight plan, we could probably do this. It became a much more collaborative effort."

Observation 13. In contrast, 6 months later, after the start of the expanded NRP, this same ATC Coordinator noted: "The problem with the expanded NRP is that there's no feedback to the AOCs. Nobody's getting smarter. ... When we went to free flight on Jan. 9, we cut off the feedback loop for those flights filed under the expanded NRP. ... How do we get this local knowledge that the TMUs and controllers have out there for the dispatchers and pilots? ... There are problems in the ATC system that I don't know about. I need a mechanism to get feedback. ... How do we give the airlines more timely

information? Depending on where they're going on which day, how do we get the information to everybody? How do we all get the same picture?"

Observation 14. The assumption behind free flight is that "if the airlines create a bottleneck and for 3 days in a row they get delayed, they'll change. They'll change the departure time or file a different route. Under free flight, we're leaving it up to them to find a solution." The assumption, in other words, is that free flight represents a "free market" environment in which businesses will respond to problems in order to remain competitive. Upon implementation of the expanded NRP, however, new problems arose that resulted in consistent inefficiencies for certain flights. The airlines were often very slow to respond, taking weeks to recognize and react to such problems.

Observation 15. TMO: "We don't even get a listing of who flew NRP the day before so we can review it and see what are the trends."

3.4 Results and Discussion

This data collection session elicited a wide range of results that are of potential value in guiding future directions for research and development. These are outlined in the sections below.

3.4.1 Benefits Associated with the Implementation of the Expanded NRP

On the whole, the AOC staff for this airline were very positive about the impact of the expanded NRP:

- "I think it's paid some big dividends for our airline and the whole aviation system."

The basis for this assessment is data such as the following, which indicate the level of usage and the estimated savings from the use of the expanded NRP for one month by this airline. For example, during that month, the airline's ATC Coordinators requested a total of 459 NRP routes through ATCSCC, and 260 of these were approved for filing. An additional 2355 flights were filed under the expanded NRP by the responsible dispatchers. Thus, there were a total of 2615 flights filed under the NRP. (In this airline, ATC Coordinators handle any requests for NRP routes through ATCSCC, while the dispatcher responsible for a flight is in charge of filing it under the expanded NRP if desired.)

The 260 flights filed through the Command Center were estimated to save \$55,160 in time (estimated at \$40/minute saved) and \$14,218 in fuel (at \$0.58 per gallon), while the remaining 2355 flights saved \$339,880 in time and \$94,060 in fuel.

3.4.2 Areas for Improvement

The ensuing discussion did, however, lead to a number of suggestions for how to either further improve upon the expanded NRP, or to develop new programs that provide the airlines with additional flexibility to meet their business needs.

3.4.2.1 Flexibility

In terms of a desire for greater flexibility, one concern is that the expanded NRP applies to only a subset of the routes flown by this airline:

- “There are all kinds of other routings that we are mandated to fly and we have very few options. We have really fewer options in those markets than we do in the markets with preferred routes.”

In particular, this airline flew only about 500 flights per day that met the guidelines for the expanded NRP at that point, out of a total of 2690 flights. (Many of these additional flights are too short to be covered by the official preferred route system. Nevertheless, many of them have routes constrained by the ATM system.) An example of one of these other highly constrained routes is:

- “Stewart-Newburg to Atlanta. We are required to come out of Stewart, north over Weard Intersection into Boston Center, back in over Lake Henry and Phillipsburg, New York Center, into Cleveland Center, then back into Indianapolis Center and back into Atlanta Center. Sometimes we get into Washington Center, sometimes we go through six Centers to get there. Nobody wants us in any of those areas. We’ve been trying to deal with New York Tracon to take the flights across TRACON airspace, which we think is much more efficient. They have their own problems, but we have flown that route for 4 or 5 years, which is 60 or 70 miles further than we want to go and in the wrong direction. So, although that is not a published ATC preferred route, we have no flexibility in what we can do and what we can’t do.”

A second concern is the 200 mile constraint imposed by the expanded NRP, limiting flexibility (for the first 200 miles and the last 200 miles of a flight) in planning economical routes:

- “We would like to see more work to do away with the 200 mile regulation. That would give us a lot of flexibility.”

A third concern deals with groundstops and delays. The expanded NRP provides flexibility in the routing, but not the launching of flights:

- “Where we get into problems is with program delays. Half an hour here, 45 minutes there, because the arrival rate is reduced in a city. That’s the kind of thing where we would rather launch and keep the pressure on the system up there and make them land us, rather than have gaps in there and be 45 minutes late because they held us at the gate.”

A fourth concern is prioritization:

- “If you’re going to divert 3 of out 12 flights to Newark, we want to tell you which 3 we want to go. We don’t want you to tell us which 3.”

Regarding prioritization, however, there was a recognition that there are additional concerns that make it infeasible to respect the airlines’ economic concerns:

- “A lot of times ATC has no choice. You may be at 10,000 feet and I may be at 20,000 feet. Or the flights may be coming in over different fixes.”

A fifth concern is a desire to take advantage of variable speeds. Like the issue of prioritization, this issue requires enhancements at the airlines and within the ATC system:

- “Another consideration is the ability to slow airplanes down or speed them up. We are already doing that to some extent. In fact, our new flight planning system will be based on that.”
- “As an indication of its significance, we just got a little blurb saying that our systems analysis staff identified 600 flights the other day that were available to slow down a little bit because they were estimated to arrive 10 minutes early because of the winds. We weren’t able to slow any of them down in part because the ATC system doesn’t like us slowing them down.”
- “No, they like .80 and they like .80 for everybody.”
- “They do, and they recognize an airplane as a certain speed, or operating at a certain speed. And we try to operate at that speed in the terminal area, in the arrival and departure areas. Enroute, however, I think you should be able to get away with slowing down or speeding up. If you’re in line for arrival with everybody else and you slow down, obviously everybody behind you is going to have to do that. With current technology, ATC doesn’t like that.”

A sixth concern is runway assignment. Solutions again would require changes within the airlines as well as the ATM system:

- “As dispatchers, we don’t really get involved in ground operations that much, but that’s one of the real big cost items that we have. Taxi times, landing on runways where the plane has to taxi a long way, I think that we need to look at that in more detail than we do.”

3.4.2.2 *Feedback*

The participants also suggested that, in terms of internal airline operations, as well as for overall program evaluation, there was a need for better data collection and evaluation:

- “We suffer from not really having a method to track what we are actually doing. We know what we plan. We know what savings we expect from what we plan, but we haven’t really come up with good ways to determine if we’re really achieving that.”

There is a similar need to provide better immediate feedback to help individual dispatchers modify flight plans on a given day and to learn in order to make future improvements:

- Moderator: “What do dispatchers know about what resulted from the expanded NRP?”
- Dispatcher: “If I’m not too busy doing other things, I might glance at my graphical screen to see where everything is, but if I don’t do that, I really don’t know what’s happened to a flight unless the pilot calls. You know you’ve tried to plan the flight the most economical way. If they haven’t called you, you don’t really know whether they are on that route or whether they have changed the route but have chosen not to call you.”

3.4.2.3 *Computer Support and Information Exchange*

There are a number of areas where dispatchers, pilots, traffic managers or controllers need better tools to make better use of the NAS.

Flight planning tools. One area where improvements are needed is in the design of flight planning systems that fully take advantage of the flexibility offered by the expanded NRP:

- “We are limited by our computer system. We still are limited in filing land-based nav aids. We do directs in between them, but we don’t have the capabilities of doing Lat-Longs. I see some very big benefits in doing that. We’re hoping to have a system at some point in the near future that will allow us to do that. Right now, however, we’re still

filing VORs, maybe directs in between them, but that still requires you to do a certain amount of zig-zagging instead of using the optimal profiles.”

Enroute flight management tools. A similar problem arises for flight crews while enroute. When offered a direct route by ATC, they have no accurate source of information onboard in order to compare their current route with a direct routing. Even if they do talk with the dispatcher:

- “It’s a very cumbersome task for the dispatcher to give them direct numbers. It’s unfortunate. You actually have to insert the route one piece at a time. We also run into problems because, if it exceeds 900 miles, you’re getting an average wind in the middle. You may think that you’re getting some good information, but in reality you’re not.”

Information on special use airspace. One particular area where better information exchange would be helpful had to do with special use airspace:

- “Jet 110 goes straight across the middle of White Sands, into the military airspace around Edwards. There is a little tiny note on the chart that says: ‘Not available most days.’ We essentially avoid it. I did some work with Albuquerque Center a while back and they were going to provide us with that information on a daily basis. We never could get it worked out so that we could really utilize that. It’s just a small part of the total puzzle, but it cost us money. We file north of it or south of it all the time. Even though we don’t have a real big operation in that region as compare with American, it still costs us money.”

3.4.2.4 Coordination and Information Exchange

Experience with the expanded NRP has also indicated a need for better coordination between AOCs and the ATM system. One such issue has to do with predictability. To be effective, dispatchers need to know when Centers are going to reject certain routes:

- “There are times where I will sit for 4 or 5 hours and file NRPs and watch Miami Center or Jacksonville Center reroute them back to the preferred route. They get them out of another Center and they’ll say ‘no, we want them over here,’ and they’ll move them over. I’ll see half a days worth of this and then say to myself: ‘This is making extra radio work for me, with the crews calling me back and forth. I’m just going to put them on the preferred route. That’s what the ATC system is going to do with them anyway.’”

While some of these problems might be predicted by AOCs by looking at the information available on weather displays and the ASD, others clearly require input from the involved Centers:

- "It may not be weather in that part of their Center. It may be in a different part that's compacting traffic all the way over, or it could be an occasion where it's just a manpower problem, where they don't have time to process the heavy traffic with the manpower they have, so they want to line everybody up and bring them through."
- "We really don't have a good handle on the traffic bottlenecks when we do have problems. It all gets back to not having the data on what they're actually doing. We need to know how they are reacting to a situation."
- "I need to know from ATC where the choke points are, where they're going to move somebody or where's the bad spot is today, and whether a bad spot today is a bad spot tomorrow. I need a forecast from ATC that says: 'Hey, we're compacted here, but you can have this NRP route all the way to there.' We need to know that ahead of time, as much as they can predict that for us."
- "What we really need is an NRP forecast for the day from them. Our workload increases if we have to change our flight plan six times on an NRP route. It's an aggravation to have to go back and change every one of those. You've got to cancel your old strip, probably add fuel to your flight plan. If we had a little bit better forecast, it would help. A lot of times, thunderstorms in the summer are not very predictable, but there are obviously times when there are lines moving that let you get a pretty good feeling that ATC won't want anybody there today. If ATC could just let us know ahead of time about these cases, we'd work around them. But we need to know how they're going to deal with a problem."
- "They don't have to pinpoint things for us. If they could just say 'today's NRPs we prefer south of Walnut Ridge or north of Walnut Ridge,' then we could evaluate it from there. Or you know: 'Fly east of this line today, or fly west of it, that's our forecast.' We certainly can't hold them to that, but it would help if they would just share their ideas. The guys in the Center know when they're going to get hurt. It would help if they could just give us a clue as to when they're going to get hurt and what they're going to do with about it, we'd try to work with them on that."
- "Right now we sometimes think we're doing something good when actually we're doing something bad. For example, we may be bringing

a flight in over a fix where they're having trouble fix balancing. Consequently the flight gets put into a holding pattern. We think we're doing an economical route when we're not. We don't have enough information."

- "I don't know about how much ahead of time we would be able to do that, but even enroute if they are a half hour away from the big bank in Atlanta and they see Macey's going to be inundated, that they're going to have to hold six flights out at Macey, that's good information for us to have. Anytime I can tell the crew what's going to happen to them before they get there benefits us greatly. Then the flight crew is on our side to begin with. They're going to hold longer. They're going to be more comfortable with what we're telling them rather than screaming at us: 'How come we're holding?'"

An important concern with such forecasts, however, is that

- "ATC tends to be very conservative and say: 'Hey, we might have a problem here today so we're just going to say that you guys shouldn't file that today.' If they could provide realistic data when there was a real need to avoid something, we wouldn't do it."

An example where this type of information exchange is happening now is with an "economy" route that this airline has worked out with three Centers:

- "In our market from Atlanta to South Florida, essentially what we do is we fly two routes. We've got the preferred route and an economy route negotiated with Atlanta Center, Jacksonville Center and Miami Center because we know that it's more efficient to go down the East Coast than it is to go down the West Coast."
- "It's automatically approved and they allow us to file it under most conditions. We do have certain conditions where we can't. If there is a missile launch at the Eastern Test Range, they don't allow us to file it. The same thing applies if there are thunderstorms. So there are times when they'll send us a message and say, 'go back to the preferred route,' and we comply with that. They usually do let us know when there's a problem through the Command Center."

Shared Displays. In addition to providing information such as NRP forecasts, it was also suggested that there is a need to provide shared displays so that AOCS and ATM staff are looking at the same information when exploring and negotiating routes:

- “There are big benefits from us looking at the same information that ATC is looking at. We don’t always interpret it the same way, but looking at the same product has a lot of benefits.”

3.4.2.6 Training

The implementation of the expanded NRP has highlighted another barrier to actually achieving the full benefits from air traffic initiatives: Inadequate training. Specifically, many pilots do not sufficiently understand the implications of filing under the expanded NRP:

- “I would estimate that only 60-70% of our pilots understand the expanded NRP.”

The net result is that pilots frequently accept direct routings from ATC once enroute, even though the AOC has determined that, based on the best available data, the filed NRP route should be more efficient:

- “They’ll accept a lot of directs. We’ll have filed them on a pressure pattern economy route but they think direct is always better, or higher is always better. We’ve tried to get that information out to them, but you know, there is a mindset out there among the pilots that we’ve got to fight against.”
- “A lot of times the flight crew will report to us on a long haul flight. They’ll report over some point where they are not supposed to be. We’ll call and say: ‘Why are you there?’ They’ll respond: ‘Well, ATC offered me direct.’ When ATC says they’ll offer a flight crew direct, it’s like holding up a \$100 bill. We’ve caused diversions before because of that. They’ve refiled direct while enroute and gone way off the filed NRP route, losing the wind pattern, with the result that they are 3,000 or 4,000 pounds short. Those flights have had to stop short and get fuel.”

This problem is further aggravated by the inconsistencies in the data available to the flight crew through their FMS and the data available to the dispatcher:

- Dispatcher: “They are very comfortable with the FMS. We know that our flight planning system is more accurate than their on-board system, unless they have plugged in the winds down line that are on the flight plan. I don’t think that happens a whole lot.”
- Moderator: “Do you ever get into discussions where you’re saying ‘my data says this’ and they say ‘theirs says that’?”

- Dispatcher: "Oh yeah. That happens often. We may have an average wind component of 50 knots and they maybe just started between that fixed pair and have 80 or 90 knots in their face. They'll say: 'This is wrong.' You have to explain to them that this is an average of the entire [route between the] fix pair, that the wind should decrease as they go further. Sure enough, you don't hear from them again, so it's obviously what happened. They are much more comfortable with what they see in their own box than they are relying on us. I guess that's just human nature."

3.4.2.7 Other Capacity Constraints

A number of the issues discussed above have implications for determining system capacity or the efficient use of system capacity. Although it was not the primary focus of this session, the participants did outline other capacity constraints of concern. First, they emphasized the critical importance of capacity limitations in considering future ATM initiatives:

- "I think they should continue to look at and develop ways to increase capacity because that's really our limiting factor. Weather as well, maybe, but in essence it's capacity."

Relevant issues included gate and runway capacities, as well as sector and cornerpost loadings. One important question raised had to do with when such limitations are due to controller workload limitations rather than physical or procedural constraints. As an example:

- "It would be nice if ATC had the flexibility where they could move their resources to handle different areas, rather than have four cornerposts, to be able to move some of those resources when they have a heavier demand coming in over Rome, having two controllers with two sectors working that area, as opposed to one. I don't know how that would work, but it would be nice if they could put manpower in that area when it's needed, with less manpower in other areas."

3.4.2.8 Organizational Problems

Another concern raised during this data collection session had to do with inconsistencies in the ways different Enroute Centers deal with air traffic:

- "There are 20 Centers out there and every Center might as well be in a different country, because they all have different moves and different regulations and they don't necessarily get along with each other. They have their letters of agreement (MOUs) out there that we know nothing about, and it's just a big mess. I think that sometime in the

future, they need to think about consolidating some of those Centers and running them more consistently. It's a big problem."

- "When we deal with them in one Center we'll deal with an airspace and procedures guy. Then, in the next one, it's a TMO and in the next one, it's somebody else. They don't talk to each other. so if you work out something in one Center, that's fine with that Center, but now you've got to go to the next Center and you've got to work with them. We need a means where we tell them what we want to do and then they work it out, as opposed to us trying to work out many, many different agreements."

An example of the value of working out problems with several Centers at once was then discussed:

- "We recently took a group from Cleveland Center and a group from Indianapolis Center and some representatives from their tower in Cincinnati, along with military representatives. We all sat down in Springfield, Ohio and talked about the problems we have in Cincinnati. They came up with solutions that were amazing because they had the authority to make some decisions. We came up with some real good things there. We came up with some new departures out of Cincinnati. We reduced the mileage on a lot of our routes. We decreased some of the runway problems we had by developing new departures. Those things can be done, it's just that you need to somehow get these groups together so that they can talk to each other."

3.4.2.9 Dispatcher Workload Problems

Finally, another barrier to full use of the expanded NRP, and a potential problem with other future programs that give the airlines more flexibility, deals with dispatcher workload:

- "We get into a workload problem at times. Yesterday is a perfect example. I had a lot of fog, flights holding in Little Rock, Richmond, and in and out of Florida. There was a significant savings if we filed down the East Coast of Florida, but there was an hour period where I let flights to Miami, Lauderdale and Palm Beach run on the preferred routing because I didn't have time to go in and look and analyze things. They needed the releases. I was going to delay the flights if I didn't get them out in a hurry, so the excessive workload stopped me from saving a little bit of money yesterday."

Furthermore, since the airline is taking more responsibility when filing a flight under the expanded NRP (since the ATM system doesn't review such

flight plans for potential problems), the dispatcher routinely has a greater workload under this program:

- “It’s a high maintenance program. You’ve got to talk to the crews more frequently. You’re taking a little bit more responsibility on yourself when you’re filing NRP routes, so you’ve got a little bit more checking to do. If I’m going to file somebody at 35 on an NRP program, and 35 gets bumpy, now he’s got to drop down to 31 at Indy Center and they don’t like that, so they’ll want to scoot him around inbounds or give him a 90° turn somewhere. Then it’s me that’s held accountable, not the pilots. It’s high maintenance. I’m paying more attention to those flights. I’m talking on the radio more frequently.”

The importance of this extra work is further emphasized by the following example:

- “If I’ve got a 1,200 pound savings on an NRP route , and I’ve reduced his fuel and just fueled him with minimal fuel for that NRP route and then all of a sudden he’s switched back over to the pref route, then I’m taking a delay at the gate or there is a pilot who wants to stop somewhere.”

3.4.3 Regulation of Airline Performance in New ATM Initiatives

A number of the points made above suggest the desirability of giving the airlines greater flexibility in making decisions about when to launch flights, how to route them, etc. In discussing such revisions to the design of the ATM system, however, a critical question was raised:

- What rules and procedures will provide greater flexibility while at the same time ensuring safety and overall efficient use of the NAS capacity?

The major focus of this discussion was the problem that what is a good decision for one airline will not necessarily always be a good decision for the overall system.

Two related questions are:

- Is a neutral “referee” required to make decisions that ensure safety and efficient use of system capacity?
- How and when should that referee become involved?

While these questions go beyond the focus of this particular data collection session, some pertinent insights were provided:

- “That’s where I have a problem with collaborative decision making and with a flow based on arrival times. When and if this ever comes

into effect, it will be the carrier's responsibility to keep a flight at its departure until it believes the flight can leave and actually land at its destination. I think we're going to find it hard to delay departures, because we want to get airplanes in the air. If they get in early and somebody spansks our hand, well, okay."

- "Let's say we start doing that. We wait for the feedback that we're having problems with our strategy for launching flights. The issue is, are we also cutting our safety margins? You could say: 'It's just a divert.' But is that changing something about the decision to divert? Is it saying: 'I'm going to risk hanging on a little bit longer because I really want to get into that airport?' We're changing the pressures on the people making the decisions. Where is that strictly an economic decision, and when does it start to be gradually more and more of a safety issue? Because it's not a clear cut line between the two."

As an example it was suggested:

- "Suppose ATC's monitoring the overall safety of the system, and let's say the FAA has a criterion that says that we don't want people to be making diversion decisions with low amounts of fuel all of the time since that's not a good policy from a safety point of view. They would have to track how often we are doing this, and if they see that a carrier is pushing the edge of the throughput margins, they'd have to say: 'Wait a minute. We want you to back off on that a little bit.' How would that negotiation work? Do you see them coming back and saying to you: 'Limit your throughput.' Since they have a responsibility for overall system safety, how are they going to decide?"

It was also pointed out, however, that the airlines already demonstrate some ability to self-regulate their decisions effectively:

- "Don't get the impression that we don't hold flights for poor weather. When we're going to Dayton or Columbus or South Bend or Grand Rapids, frequently they'll be below minimums with no ground stop on. We still choose to stay on the ground. So we already do a considerable amount of self-regulation ourselves."

3.4.3.1 Alternative Control Parameters

The discussion above suggests one (possibly controversial) means of control by the FAA to help ensure safety: Regulating average landing fuel levels and monitoring actual landing fuels to ensure that airlines are not routinely pushing too close to the edge in terms of safety. Another type of control parameter was also discussed in the context of cornerpost loadings when there is a reduction in capacity:

- "The FAA could make percentage calls. If Delta is 72% of the operation in Atlanta, if they would like to move ten flights from Macey to Rome over the next three hours, Delta could move seven and ValuJet could move one flight, and so on. With this strategy, you would start to assigning slots to each of those cornerposts, with each airline having a percentages of those slots if they chose to take them."

Potential concerns with this type of control parameter were also discussed, however, based on past experience with such a strategy:

- "They've tried to fix loading and we really didn't like it too much. That was the fix loading program that we had for Atlanta. We had delays every day. It did not work because it wasn't managed well. They used it as a way to manage the capacity and it wasn't valid, it just didn't work. They would take our flights every day and delay them. Say we had a push of 60 airplanes coming into Atlanta. They'd delay twenty of them because of demand over the fix. They did that every day. In contrast to that, now we've got a scenario where we do some airborne holding. We encouraged everyone to use holding to a certain extent, because we want to have airplanes available when the capacity permits them to land."

In short, the experience was that the estimates used by the ATM system to initiate ground delays were too conservative:

- "If, instead of holding those twenty flights on the ground, we had launched all twenty, we would have actually had only five that would have had some airborne holding. Why should we delay twenty flights when in fact there would only be five of them late. We can't do anything with them if they are sitting on the ground in Raleigh or Greensboro or whatever. If we've got them up there holding and there is a slot available, if somebody else is late or whatever, then we keep capacity up. Maybe the ATC specialists suffer from a lack of real time information over there. If they had real time information and knew exactly when everybody was going to come over those fixes, maybe they could manage better."

A suggestion to help deal with this conservatism and this lack of access to real time information was to make decision-making more collaborative:

- "We could be involved in the planning with them and say: 'Hey, don't cut at this number, let's use this other number because we don't care if some of the flights have to hold. We'll handle that ourselves. How about if I come up there with an hour and a half of hold fuel and if you get me in, you get me in?'"

- “You’ve got some traffic manager who’s looking at all the data he has available and he says: ‘Delta, you’re taking up 50% of our traffic for the next two hours and we predict there is going to be reduced capacity. You can either send all your planes as long as we agree ahead of time about what they’re going to do if they can’t land there, making sure there is a safe place for them to go.’ That way, you have a choice, but in the worst case, you pay the penalty and can safely divert. But my advice, based on the information I’ve got, suggests you ought to cut back. Now it’s my choice.”

“They’re saying that, if they’re right as a traffic cop, when the planes start arriving, I’m not going to get 100% of mine in there. American’s going to get their percentage in and I’m going to get my percentage in. As another example, they might come up and say: ‘We recommend you delay Flight 345 for 2 hours and 40 minutes.’ I could then say: ‘How about if I delay that one an hour and a half and stick another hour and a half on Flight 262 over here.’ This way they’re giving me options to work with.”

- “Separate the roles here. One is information: ‘There is a potential problem here.’ Let us judge whether we concur with that. The other is: ‘Here’s a recommendation.’ Let me decide how I want to deal with it. They become an advisor, like some sort of counselor.”

3.5 Summary and Conclusions

This knowledge acquisition session provided a rich set of data for identifying issues related to the design of the current and future ATM systems. The issues discussed included procedural changes as well as areas for technology development, and dealt with concerns over organizational behavior as well as individual performance. For the convenience of the reader, we summarize the issues here in the order in which they are discussed in the report, rather than attempting to prioritize them.

3.5.1 Scenario Development

It is clear from this knowledge acquisition session, as well as others we have conducted, that specific scenarios, properly used, help elicit very useful information from subject-matter experts. One of the challenges in developing future systems will be to identify all of the relevant scenarios and to ensure that the full range of relevant expertise is accessed.

3.5.2 Benefits Associated with the Implementation of the Expanded NRP

The data presented indicate that, for a single carrier during a single month, the total estimated dollar savings from the NRP amounted to over \$500,000. This fact alone, if substantiated by data from other airspace users, indicates the potential gains to be realized from providing carriers with greater flexibility (see below).

3.5.3 Areas for Improvement

Flexibility: The quotations presented earlier exemplify some of the constraints imposed on flights in the present system. While some may be the result of ingrained conservatism in the ATM system, some are clearly the result of mismatches between the present strategically-based system and the loosening of strategic constraints under the expanded NRP.

What we are seeing with the expanded NRP is one of the first attempts to implement a *hybrid* system, in which management may be either by directive, by permission or by exception (see also report no. 5 in this volume). It is clear that, although this is viewed as a step in the right direction, users feel they need more flexibility, especially with respect to timing, diversion options, speeds, and runway assignments and routings. Dispatchers recognized the problems ATC would have in granting greater flexibility, but they also point out the costs of operations under present constraints.

Feedback: The issues of information management and information sharing have been pervasive in the data we have collected in support of these studies. This is not only a problem in ATM/airline communication; it is as serious a problem within the airlines themselves, and within the ATM system. As authority begins to be diffused throughout the system, more information is required in more places, to be used by more people for decision-making. This is seen in many of the following sections of the report.

Computer Support and Information Exchange: Better tools are needed if human operators in the system are to make better use of its resources. The examples presented above identify decision support tools that are needed to accomplish specific dispatching tasks, with a particular emphasis on the need to support information dissemination and cooperative problem-solving.

Given the large amount of information presently resident in the system, and the limited capacity of human operators to deal with it at present, we believe that the area of information dissemination and representation is perhaps the most critical and potentially productive area for intensive exploration and development of new aiding technologies for a future ATM system. Such information exchange is critical to both individual and group problem-solving.

Training: The observations from this group refer to the training and education of pilots, but this is suggestive of broader issues as well. It is clear,

for example, that the Air Traffic Management system has an incomplete understanding of the needs and priorities of air carriers. The comments in this session also suggest that some ATC facilities may also lack knowledge of how other facilities have coped more effectively with the similar problems. (See Results: Capacity Constraints; Organizational Problems).

Other Capacity Constraints: The issue of extending the scope of flexibility to surface movements is one that may require different strategies as well as different technologies for its solution.

Organizational Issues: It is regrettable, in some respects, that the original NRP, which required a good deal of discussion and interaction among all system participants, has given way to the expanded NRP in which these participants are expected simply to make decisions without such consultation and discussion. These data suggest that ways must be found to enhance and reward a more communicative, consultative, and therefore cooperative style of operations in the NAS.

Dispatcher Workload Problems: The issue of simply transferring, rather than mitigating, operator workload is discussed under this heading. Care must be taken to alleviate workload under high-intensity conditions, not to transfer it from one set of system participants to another. One type of solution is for long-distance conflict prediction software tools, when they become available, to be made accessible to both ATM and AOCs.

3.5.4 Regulation of Airline Performance in New ATM Initiatives

The overarching issue of mediation among participants in a more flexible system must be approached by system designers. Given the competing objectives of users, does there need to be a neutral "referee"?

There is no question that the ultimate locus of control and the authority to assure safe separation of aircraft in a future system will reside with ATM staff. Just as aircraft automation can foreclose or render less effective pilot authority, however, the rules, procedures and software for a more flexible ATM system, unless carefully designed, may foreclose or make less effective the authority of air traffic managers and controllers under some circumstances. This is a system integration issue that requires further research, but the dimensions of the issue are evident even in the research done to date. Cooperative decision-making was suggested as one way to reduce problems with real-time decision-making in this area; post-operations analyses of system performance was identified as a second, complementary approach.

It is clear, however, that the functional requirements for a future system must include at least an outline of the policies and procedures under which the system will function, and that these functional requirements must be in place as a guide for the design of the equipment which will assist human operators

in the operation and management of the system. Though the philosophy of human- or user-centered automation has been accepted by at least some system proponents, such a general philosophy must be particularized in terms of the ATM system before the design of its architecture can be made final.

3.6 Recommendations for Further Research

Based on these results and our other research to date, we make the following recommendations for further work.

- Expand research on the overall functional requirements for a future advanced ATM system embodying management by permission and management by exception, to serve as guides for the development of aiding technologies to be implemented in such a system.
- Accelerate and expand research on information management for a future ATM system in which responsibilities and authority are more widely distributed among system participants. This research should include:
 - Information requirements under a management by permission paradigm;
 - Information requirements under a management by exception paradigm;
 - Methods and technologies to improve the sharing of information;
 - Means by which information assimilation can be enhanced;
 - Information representation technologies and methods suitable for:
 - Airline Operations Centers;
 - Pilots in flight;
 - Traffic managers;
 - ATC controllers operating under management by exception rules.
- Search for ways to improve collaborative decision-making among system participants in addition to studying technologies that will more effectively share relevant information among those participants.
- Continue and if possible expand research into ways of providing more flexibility for airline operations.
- Explore the issues raised by the probable need for a neutral “referee” or arbitrator in a more distributed future ATM system, and examine proprietary and competitive issues embedded in information requirements, since these are the issues most likely to inhibit sharing of information in a more distributed system.

HUMAN-CENTERED TECHNOLOGIES AND PROCEDURES FOR FUTURE AIR TRAFFIC MANAGEMENT

4. HUMAN FACTORS ISSUES IN THE DESIGN OF A FUTURE FREE FLIGHT ENVIRONMENT: DEALING WITH A MIXED LOCUS OF CONTROL

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4.1 Introduction

The goal of this project has been to provide NASA's Advanced Air Transportation Technologies program with input regarding a number of important human factors issues pertinent to the design of the future air transportation system. To collect relevant data, a scenario was designed to study critical features of a possible future system, and was used to provide the context for a conceptual or semantic-level evaluation by a group of practitioners representing different system perspectives. The results of this conceptual evaluation, which included two controllers, one dispatcher and one pilot, are presented below.

4.2 Methods

The scenario was first reviewed for accuracy and realism with three traffic managers from the airspace used in the scenario. It was then presented to the participants for a conceptual evaluation as an incident report, outlining a situation purported to have arisen in 1997 (see report no. 2, pp. 2-19-22 in this volume for the scenario and incident report). The participants were asked to review this incident report, and then to play the role of a review team evaluating the report.

4.2.1 Scenario Characteristics

This scenario is based on a problematic situation that already exists in Oakland Center as a result of responses to the expanded National Route Program (NRP). Specifically, in order to accommodate airline requests for more flexibility in selecting

routes during preflight planning, in Oakland Center airspace high altitude traffic is being allowed to criss-cross through arrival lanes:

- Traffic Manager: "We're seeing a funnel effect. Where it used to be we would have two streams down to the Los Angeles basin, now everybody aims for Arenal. This works OK a lot of the time, except when things go wrong. When they go wrong, you suddenly have a whole herd of airplanes pointed at one point and a last minute change such as the need for an increase in the miles-in-trail or an airplane taking a wrong clearance, or any number of things, can cause a serious problem because you have a real concentration of airplanes. Suddenly you have to pull the plug to deal with it, whereas before at most you had a miles-in-trail situation, you had a bit more leeway. Even when it's workable, it puts a burden on the controller because it's not something they do every day.
- "If you just take those aircraft crossing Coaldale at 39,000 feet, they've got to cross Modesto at 24 and you've got airplanes southbound at 29, 33 and 37, [and] northbound at 31, 35. It's pretty much like a charge. It makes it real hard to thread that guy from 39 down to 24 and at the same time do all the things you have to be doing. If it was just one airplane to get through anybody could do it, but we're talking multiple airplanes, because it's the old push time and they're all coming at once. Twenty minutes later there may not be an airplane in the sector, but for those 20 minutes it gets wild and crazy. Not having them on the routes the way they used to be has caused a lot of heartburn for the controllers. They're having trouble getting them down."

Thus, although Oakland Center is allowing flights on this user-preferred "economy route", it is problematic because it results in high altitude traffic flying through airport arrival lanes.

This design of economy routes is not unique to Oakland Center. It has been a common response by a number of Centers to accommodate the desires of the airlines to fly more efficient routes. Furthermore, the problem of high altitude flights on such "economy routes" crossing through departure and arrival lanes is not an isolated occurrence. Other Centers are dealing with exactly the same problem. Some, like Oakland, are able to cope with the added complexity and thus allow such routes. Others, like Chicago, have found that approving such routes reduces departures by as much as 20%, and therefore are limiting such routes:

- Traffic Manager: "For certain flights over the top of O'Hare, Chicago Center has always preferred that the traffic be routed over Badger in order to avoid having enroute traffic cross the departure lanes. One airline, however, prefers (and began filing) these flights over Iowa City-Waterloo under the expanded NRP. Such flights criss-crossed through the departure lanes, creating a 'very tricky, complex operation' for ATC. This raised an interesting question: Do you let 3 or 4 planes cross at the cost of slowing departures by

about 20%? This tradeoff is particularly interesting given such flights were most often slowing departures from Chicago of flights by two other airlines."

Thus, this scenario clearly represents an important general situation that must be considered in designing a future air traffic system which attempts to accommodate the desires of the airlines for more flexibility in selecting routes for their flights.

This scenario presents a situation that already exists, and that can be expected to continue in any future Free Flight environment. The simple fact of the matter is that there are many locations where the most economical routes cross through airport departure and arrival lanes. Thus, NASA needs to ask:

- What can be done to improve the ability of the system to deal with such situations, so that the airlines' desires can be safely accommodated more often? (New technologies? New procedures? Changes in sector designs? Changes in controller staffing models?)
- What can be done to improve (pre-flight) information exchange so that the airlines know when a flight along an "economy route" is likely to be vectored off that route in order to avoid conflicts with arrivals or departures at an airport (since, given such information, the airline might choose an entirely different route to begin with)?

This scenario also explores issues, beyond the existing situation, that have arisen as a result of efforts to give the airlines flexibility in pre-flight planning, however. To explore other issues associated with the design of a future Free Flight environment, we added another form of flexibility to the scenario: The ability for an individual flight to change its route while airborne, without having to seek permission from a controller.

The net result is a scenario in which high-altitude Free Flight traffic (which is monitored but not controlled by ground-based controllers) is crossing through departure and arrival lanes with traffic that is under the control of ground-based controllers. Within this setting, we then introduced an incident: One of the Free Flight aircraft encounters turbulence and elects to change altitude. This produces a potential conflict with an arriving aircraft, which the involved flight crews and controller fail to resolve before minimum separation standards are violated. (The problem is resolved without a collision, however.)

Thus, this scenario has a number of important characteristics:

- At a strategic level, there is a potential goal conflict: The desire for efficient high altitude routes potentially conflicts with the desire for maintaining airport arrival and departure capacities;

- In trying to accommodate these two desires, a situation arises where there is a mixed locus of control for the traffic involved. Some of the traffic is under controller supervision, while other traffic is flying under Free Flight rules;
- As a result of unexpected turbulence, one of the Free Flight aircraft makes an altitude change, resulting in a potential conflict;
- Because this potential conflict arises in a sector with heavy traffic congestion, and because of the complexity of the situation with its crossing traffic and the mixed locus of control, the affected pilots and controller fail to detect and deal with the situation in a timely manner.

4.2.2 Subjects

Prior to the actual use of the scenario, three traffic managers from the affected airspace were asked to review the scenario. Then, for the conceptual walkthrough, two Center controllers, one airline dispatcher and an airline pilot served as subjects.

4.2.3 Procedure

Briefly, the subjects:

- Were told that their role was that of a review board responsible for evaluating this incident and for making recommendations for future system enhancements (including the development of new technologies, changes in roles, responsibilities, procedures, etc.);
- Reviewed the scenario prior to the day of the data collection session;
- Met and worked through the scenario as a team, discussing relevant aspects of the incident as it unfolded, and identifying important issues that arose at different points in the scenario. Members of the research team probed for further details as the scenario walkthrough proceeded, to help ensure that the critical questions were addressed. These interactions were tape-recorded for later analysis.

4.3 Results

Based on the data provided by this conceptual evaluation, a set of recommendations was developed. This interpretation of the input provided by the participants in the study was then reviewed by those participants to ensure that it reflected their input accurately. Given the limited number of participants involved at this point, these recommendations should clearly be viewed as a basis for further discussion, rather than firm conclusions. As part of our discussion of each recommendation, we also make explicit its potential implications for future research.

4.3.1 Realism of the scenario

The participants were very comfortable with the validity of the the scenario:

- Controller: "Very realistic scenario you put together here."
- Dispatcher: "From what I see in the airline, it's also very realistic. From what we see on our ASD screens, it's very real. I don't know if there's a whole lot more you could do to make it more realistic."

4.3.2 Assumed Model of the Free Flight Environment

Based on the discussion stimulated by this scenario, the participants made explicit a number of assumptions that they were making about a future Free Flight environment. These assumptions went beyond the conditions explicitly stated as part of the incident report:

1. The traffic management organization responsible for strategic planning would identify which portions of the airspace were open for free filing of flight plans, and of that airspace, which portions were open for Free Flight while enroute. Those portions open for free filing but not for Free Flight while enroute would require flights to fly under the positive control of controllers while in that airspace;
2. This information would be communicated to the AOCs so they could plan appropriately;
3. As long as the airspace along a proposed route was open for free filing of flight plans, the AOC could simply file the desired route. If there were enroute Free Flight restrictions along all or part of the route, the AOC could still file its desired route, but the flight would have to operate under controller supervision on the restricted portions of the route;
4. The flight crew would depart knowing which segments of a flight were open for Free Flight;
5. Even for flight segments filed for Free Flight, the controller for that sector would have ultimate authority to ensure separation. When the flight entered that controller's sector, he would transfer that responsibility to the cockpit, with the concurrence of the pilot, or leave it with the pilot, if the controller and pilot felt that it was safe to do so. As part of that process, the controller would have to provide the cockpit with all of the information that was not available on cockpit displays but was necessary to ensure adequate situation awareness. That could include information about the intentions of other Free Flight aircraft and of other non-Free Flight aircraft, information about the weather, and information about possible contingencies or possible behaviors of other aircraft. (An alternative might be to have such transfer of responsibility occur at a Center level, so that fewer ATC/aircraft interactions would have to occur);

6. While flying Free Flight, the pilot could make flight plan changes without permission from the controller. He would have access to a situation display and a conflict probe system to help evaluate the safety of a change under consideration. Because the conflict probe might not have access to all pertinent information, however, the pilot would take ultimate responsibility for making a change, and as part of that responsibility would have to make sure that he or she was aware of any information and contingencies that were outside the scope of the computer's capabilities. The pilot would also have to be able somehow to inform all other aircraft of his intended change;

7. With computer assistance, traffic managers and controllers would monitor the overall situation in addition to controlling non-Free Flight traffic. If a situation was detected that required restricting Free Flight, placing flights in some area back under positive control, affected flight crews and AOCs would be informed as early as possible so that they could make appropriate adjustments. If instead a simple flight amendment was required for an individual flight, the controller would inform the crew. If appropriate, and if his/her workload permitted, the controller might give the crew several options to select from. If time or controller workload required acting without discussion, the controller would so inform the crew. Following the requested amendment, the flight would be allowed to continue in Free Flight if the situation allowed it;

8. If conditions allowed, a flight could potentially continue in Free Flight as far as the outer marker (or even gate to gate).

Explicit identification of these assumptions is important, as there are obviously alternative definitions of a future Free Flight environment, and the assumptions made influenced the participants' evaluation of the incident report. These particular assumptions reflect the views of the participants at the time of the conceptual walkthrough, and do not necessarily match the details of the RTCA report on Free Flight (RTCA, 1995).

Recommendation 1. Experience with the expanded NRP has made it clear that an important scenario that must be dealt with in a Free Flight environment is the crossing of arrival and departure lanes by high-altitude traffic. The quotes from traffic managers presented earlier make it clear that, under current conditions where individual flights are under controller supervision, this is a "very tricky, complex operation." This complexity would potentially increase under Free Flight if the high altitude aircraft were flying under Free Flight rules while some or all of the departing and arriving aircraft were under controller supervision.

As the questions below indicate, considerable study is needed to determine whether Free Flight can be accommodated under such conditions and, if so, what needs to be done to accommodate it.

Research Questions:

What procedures should be followed in such scenarios to ensure safe, efficient traffic management and control? What does it take to make the filing of such routes acceptable?

What new technologies or other changes (such as the creation of new sector boundaries, changes in controller staffing of sectors, etc.) could make such routes less of a problem?

Can enroute Free Flight be allowed in such sectors, or should such flights always be under positive control by controllers?

Recommendation 2. The situation probed in this critical scenario was not highlighted by the simulations that have been run to evaluate the impact of Free Flight on air traffic patterns, suggesting that improvements are needed in the design of such simulations.

Research Questions:

How should the existing simulation systems be enhanced?

Should empirical data be collected to evaluate the predictions of these simulations?

Recommendation 3. On any given day, routes or segments of routes will arise that cannot accommodate a particular flight at all, or that cannot accommodate that flight under enroute Free Flight rules because of weather, traffic congestion, airport restrictions, etc. Such routes need to be identified ahead of time if possible, and need to be communicated to AOCs so that they can consider the restrictions during their pre-flight planning. In essence, in a Free Flight environment, AOCs need traffic and ATC forecasts just as they need weather forecasts. In addition, a neutral referee (the traffic management system) needs the authority to deny a request for a particular route, or to deny flight under enroute Free Flight rules along that route (or some segment of the route). Such restrictions would be based on considerations of safety and the impact on overall system capacity:

- Controller: "Traffic management would determine what routes would be inappropriate for Free Flight based on predicted weather and traffic, and would program the computer. The dispatcher would send in the flight plan two hours ahead of time and the computer would analyze it. Then the dispatcher would get an acknowledgment that that flight can't go today Free Flight. Then he could do better flight planning on it. The pilots would know before they leave that they're not flying Free Flight."
- Controller: "You've got 140 major city pairs, and those are going to be your major players. So it wouldn't be hard."

Research Questions

What tools or procedures would reduce the number of situations where such restrictions would be necessary?

Can tools be developed to help identify such routes or route segments? (This includes communication tools to improve input from regional traffic management centers as well as tools that automatically look at collected data.)

Can tools be developed to help disseminate such restrictions to AOCs so that they can plan more efficiently and effectively?

If some segments of a flight are under Free Flight rules while others are not, how will transitions be handled once a flight is enroute?

Recommendation 4. The air traffic control system has to be designed to handle situations where, during the course of a flight, enroute Free Flight may have to be rescinded for some segment because of weather, traffic, airport restrictions, etc.:

- Controller: "There's going to be instances and times when Free Flight is going to have to be terminated, and weather is going to be the key time that Free Flight is going to have to be terminated for a given area, for a given time."
- Controller: "If we have a large number of aircraft involved, that falls back to the controller and they have to have the final authority. You may have the cockpit say: 'Well, I want to do my own separation on this conflict.' You have to be able to say no because there are too many involved."

Research Questions:

What procedures should be defined to handle such transitions?

- Controller: "There are situations where you could say: 'Do you want to do this or do you want to do that, like we do today. I've got traffic here. Do you want to descend? Do you want to turn? What do you want to do? Do you want to slow down a little bit?' And we'll give them multiple choices, time permitting. Now, when we're real busy, it's: 'No. You do it.' We have to build something similar into any type of flight because there is the big picture."
- Controller: "One of the things that's hard for me ... is at what point does Free Flight stop and air traffic control take over? If I'm separating one aircraft from another, do I have to take both these guys off of Free Flight? Because I can't very well give this guy an instruction based on what I hope this other guy's going to do. And add a third or a fourth or a fifth aircraft into the

situation, now do I have to take six people off Free Flight? How do I take them off Free Flight? How are these things communicated? At what point do I put them back? ... So that everybody's singing on the same page. ... Every time there's been a separation loss, it always seems to be based on some miscommunication somewhere. I think you're doing something when actually I was the one who was supposed to be."

- Controller: "This is a real good situation because you have one airplane that could easily affect 3 airplanes in a very tight space and yet these 3 airplanes are possibly flying along minding their own business, they're fine. ... To solve it, I may have to step on the toes of 6 or 7 airplanes and make sure I know exactly what their intent is before I can solve this situation. Today I could solve that with one transmission. Now it might require six transmissions before I could even begin to solve it, because there's no sense in me laying out clearances if all these other guys are going to start cranking and banking without telling me, which is the same thing as doing it and then telling me."

How will sufficient controller staffing be assured to handle such transitions from Free Flight to controlled flight?

What situation displays and decision support tools need to be given to controllers to assist them in detecting such situations and making the transitions?

What technologies are required to reduce the frequency of occurrence of the need to rescind Free Flight?

If such a segment can be identified well prior to the flight reaching that point, how can this information be disseminated to the AOC and/or the flight deck so that the operator can revise his plans if desired?

Are the points where this is going to be necessary going to occur with a frequency and at locations such that enroute Free Flight is not economical?

- Pilot: "This is the rub of the whole idea. ... If you restrict it where you start getting into the approach phase, from the outer points on in, and you are going into procedural separation there, you've basically lost most of the utility of Free Flight. ... What they [the airlines] want, they want random access all the way to the numbers, or let's say to the outer marker."
- Controller: "We'd like to see more airborne resolution. There's a lot of scenarios where it could be done easily."

Recommendation 5. Controllers need to play a dual role, as information providers and as controllers. Situations will arise where the controller sees some change that may be desirable (but not necessary) for an aircraft under Free Flight, and will simply communicate this suggestion to the cockpit without

rescinding Free Flight. The crew can then choose to act or not act on this suggestion in consultation with their dispatcher (thus allowing them to make a decision based on business concerns). Situations will also arise, however, where the controller notes a necessary change. In such situations, the controller could choose to simply issue an instruction such as: "Maintain altitude and turn right 5 degrees to maintain separation from Flight 470, then resume Free Flight."

- Controller: "If an aircraft is in a Free Flight mode and you have to issue an instruction to them, I don't consider that taking them into a structured system. I'm just resolving a conflict. ... Once the conflict is resolved, they're still in their Free Flight mode and they just continue on."

Research Questions:

How should such instructions be handled procedurally in order to make sure the flight crew knows when a controller is giving a command vs. a suggestion?

- Controller: "There's times when the pilot and controller do not have time to battle back and forth as to what's the best plan."
- Controller: "The time frame that that all takes place in, the time that the conflict resolution software generates a resolution, that's given to the controller, he digests it, and then it's sent to the crew and they digest it and decide: 'Do I act on it or not?' Things are moving very quickly."
- Controller: "Absolutely. And at closure rates at high altitude, you don't have the time span for that flight crew to second guess what the controller's doing because they don't have the big picture for the entire sector."

What technologies can assist with the detection of situations that require some prompt action? What should the role of such technology be (providing advice to the controller vs. issuing a command directly to the flight)?

- Pilot: "In the South Pacific, what they're finding is, ATC doesn't want to monitor all of the airplanes. ... All they want to do is they want to monitor by exception, which means they want to find out if something isn't going right."
- Controller: "It seems like it's a little late to do something by then. It all depends on how far apart these airplanes are. If they're in close proximity, the guy goes 300 feet, too late. By the time I get the alert, separation is already gone."
- Pilot: "This is different because we're talking the oceanic environment."

- Controller: "I can see that argument from the oceanic controller's perspective, because typically they have, you know, one stream's going west, one stream's going east, and I just have to worry about these two. They don't have flights going from every compass point to every compass point."

What technologies can assist with the resolution of situations that require some prompt action? What should the role of such technology be?

- Controller: "The conflict resolution software is only going to offer or propose a solution to the controller. The controller may or may not elect to do what that recommends."
- Pilot: "The computer can't take into account all of the variables that are going to be out there, for example weather."
- Controller: "Or non-participating aircraft."

If the controller plays a passive role most of the time in the detection and resolution of problems, will he or she be able to anticipate and deal with the exceptional situations that the computer cannot cope with?

- Dispatcher: "And yet human factors come back into play once you get beyond a certain point, because, if you're a system manager, you're not actively participating as much as you were before. The only time that you're actively participating are those high stress situations where there is an alert, people are operating at reduced separation standards because there are more airplanes in the sky, the stress level goes through the roof."
- Controller: "And proficiency comes into play. ... You're only going to be jumping in ... on an as needed basis."

How big a picture should the flight crew be given? What technologies are necessary to provide this picture? How will the differences in the data and perspectives available to flight crews and controllers be dealt with?

- Dispatcher: "The scope of the situation display in the cockpit will be a given area that they will be able to see. You guys [the controllers] will have the much larger picture as to what's going on, so I think they may think, well, the whole world is revolving around me and just 2 or 3 other planes around them, and they don't realize the conflicts with the much wider, broader area."

Recommendation 6. In order to assure that enroute Free Flight can be safely be supported with acceptably small separation distances, intent information must be available on all involved aircraft for all of the individuals with authority to change the course of an aircraft (controllers and flight crews on aircraft flying under Free Flight rules):

- Controller: "For any kind of ground-based conflict resolution to be anywhere near efficient, it must have intent. Or airborne resolution."
- Controller: "There's corridors in the Northeast and things like that where, without intent known in a Free Flight environment, it'll never become a reality because of the volume and the density of the traffic."

Referring to the loss of separation that occurred in this scenario, the participants had a number of comments:

- Controller: "The overload was caused by the fact that he was surprised. Something happened that he wasn't planning on. An airplane's moving on its own without telling me about it. That starts the whole workload ball building up. What was a very manageable situation all of a sudden now gets out of hand."
- Controller: "Today if this happens, I've got a surprise, I can handle it because I know what everybody else is doing. They're doing what they're supposed to be doing. But now there's a whole lot of question marks after all these call signs. In fact, that's how I would probably identify the guys who are in Free Flight. I'd have the computer put a question mark after his call sign because I'm not positive what he's going to be doing."

Minimally, this seems to imply that:

1. For any given sector, the involved controllers and flight crews need to know about the planned routes for those aircraft using the FMS to fly along filed flight plans;
 2. If a flight changes its flight plan, and the crew enters this change in route on the FMS, then that change needs to be transmitted to all of the relevant controllers and flight crews;
 3. If a flight changes its route, but the crew elects to "hand fly" the airplane, their intentions must be verbally transmitted to all relevant controllers and flight crews;
 4. If such intent information cannot be specified and communicated adequately, then the flight will have to revert to controller supervision:
- Controller: "You'd have to have the termination of Free Flight any time that you don't have proper [knowledge of] intent."

Recommendation 7. When a flight crew flying under enroute Free Flight wants to make a change in its flight plan (other than an emergency deviation), some agent with full awareness of the situation (including weather, the intentions of all aircraft, the actual behaviors of all aircraft, likely

changes in the intentions of all aircraft, and available contingencies) needs to evaluate the proposed change to make sure it maintains desired separation levels. If there are weather disturbances, intentions, likely behaviors, or contingencies that cannot be encoded in a form the computer can handle, then that agent must be a person.

Research Questions:

What information can actually be incorporated in a computer system that is meant to provide a conflict probe?

Should a flight under enroute Free Flight have to communicate with other Free Flight aircraft in the area before initiating a change?

Because of the potential brittleness of computer systems, and because of the need for the people involved to maintain situation awareness, should some person always be required to give final approval (with computer systems designed as support tools for that person)? Initially, one of the controllers seemed to feel that the controller could be left out of the loop when a flight was flying under Free Flight rules, with the flight crew and a computer-based conflict-probe system taking responsibility for separation unless the conflict probe detected a problem and alerted the controller:

- Controller: "You've got the midwest of the country and all that, the high altitudes under the Free Flight environment. The controller workload would be considerably gone, eliminated, if he had a ground-based conflict probe. You wouldn't have to constantly scan the scope trying to pick out conflicts because it's already being done [by the computer]."

Further discussion seemed to rule out this point of view, however, because of the likely limitations of the technology:

- Controller: [In response to the question: "Are you comfortable with the idea that the computer would automatically pass through an OK, or do you need a person to approve it?"] "No. The biggest problem I have with that, especially with Salt Lake Center, is weather. The computer doesn't know weather ... The computer doesn't know wind shifts. There's so many times that our conflict alert gets fooled, and it's based on the last heading and speed, and somebody's going through a windshear. I may have sat at that sector all day long and watched these guys, you know, headings change dramatically when they hit this windshear. The computer, at least I don't know of any way of telling that computer where the windshear is, how it's been moving all day long, and to let it make those adjustments for me in its conflict probe. At least in the airspace I work, we get these dramatic jetstreams coming down there. You'll have a 40 degree heading change there sometimes.

"So some of those things, I just don't see the computer being able to predict or really help me with. You have huge thunderstorms, and every airplane in the sky is diving for a hole. I don't know how we communicate that to the computer, and how it's going to help me do the conflict prediction through this hole. ... So if we're taking the same amount of airplanes on a normal good weather day, we're going to have twice as many airplanes in a sector now, we're going to have half as many people, fine. Now, on a bad weather day, where I've lost the aid of this wonderful computer tool, and we're back to more of the old type of communication, with deviations, with all the things going on, you're going to be right back where you are today, except that you've got half the people out there to handle it, with twice as many airplanes. That's an exponential number of delays you're talking about."

When should this person be a controller and when should it be the pilot?

- Controller: "The concept is that the aircraft would have onboard ... some sort of aircraft situation awareness around it, that you would communicate to the aircraft what your intention is to resolve the conflict, and then just pretty much, just turn control back to the cockpit again, saying: 'This is the traffic. Do you have it on your situation awareness? Once you're clear of it, resume.' So the intent would be there for the crew too, for the cockpit, in case there should be communication failure or something like that. Or, we have discussed, that the cockpit at times, given certain situations, and the intent is well known, that they would provide their own separation. ... As long as both parties agree and they accept the responsibility, then they do it by whatever means."
- Controller: "There's so many times I've got one aircraft that's overtaking another and I want to say: 'Offset a couple miles and go around him or descend 300 feet and pass him.' I'll tell him the intent is to stay level. And then I'll broadcast to the other aircraft: 'He's going to come by you and all that.' Then, that takes my complete concentration away from those aircraft so that I can work on more. ... This is one way of taking some of my workload and shifting it to the cockpit."
- Controller: "You can take a lot of workload away from the controller by shifting it to the cockpit. These are things that they need. They need the airborne conflict probe, they need to know the intent, and when you shift the responsibility, there has to be a clear understanding of the shift."

When responsibility is handed off from a controller to the flight crew, what must the controller communicate to the crew to assure adequate situation awareness (weather information, the intentions of all other aircraft, the actual behaviors of all other aircraft, possible changes in the intentions of all aircraft, contingencies to consider, etc.), and how will this be communicated (verbal communications between controller and flight crew vs. computer displays of intent, weather, etc.)?

4.4 Summary

Since the recommendations generated from the data of this conceptual evaluation are based on a small number of subjects, they should clearly be viewed as hypotheses rather than firm conclusions. They do serve, however, to raise numerous important questions that must be addressed in designing a future system that incorporates some of the goals embodied in the Free Flight concept.

Some of these questions deal with the roles and responsibilities of flight crews, controllers, traffic managers and dispatchers. Some are concerned with the definition of procedures. Others deal with issues of workload, training and the maintenance of skills. Still others deal with communication.

One question that must be dealt with is a clear definition of the information necessary to ensure situation awareness and to enable informed decisions to be made when a flight plan is to be amended. This investigation suggests that such information includes:

- The intentions of aircraft participating in Free Flight;
- The intentions of aircraft not participating in Free Flight;
- The weather;
- Possible unplanned events, including deviations of aircraft from their intentions (due to weather, for example);
- The availability of reasonable contingencies to deal with unplanned events.

Finally, almost all of these issues have implications for the roles and designs of support technologies. Such technologies include:

- Tools to support cooperative work involving traffic managers, controllers, flight crews and AOCs;
- Communication links (air-to-ground, air-to air and ground-to-ground);
- Conflict detection and resolution software;
- Cockpit and ground-based situation displays (for flight crews, controllers, traffic managers and AOCs);
- Tools for strategic and tactical planning (for AOCs, traffic managers, flight crews and controllers).

HUMAN-CENTERED TECHNOLOGIES AND PROCEDURES FOR FUTURE AIR TRAFFIC MANAGEMENT

5. HUMAN FACTORS ISSUES IN THE DESIGN OF A MORE FLEXIBLE ATM ENVIRONMENT: THE COGNITIVE DEMANDS OF MANAGEMENT BY EXCEPTION

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5.1 Introduction and overview

5.1.1 A future ATM system managed by exception

Fundamental changes are thought necessary to respond to increasing demands for capacity and throughput in the American National airspace. Proposals for dealing with the capacity and efficiency challenges to the air traffic management system usually include two aspects. One is more freedom for airspace users, and the other is more automation of traffic surveillance and conflict detection. The important residual task that will be left to human controllers is one of supervision, that is, overseeing system activity and *managing exceptions* (RTCA, 1996, RMB, 1996). The concept is that in exceptional circumstances, i.e., cases where the system cannot cope by using its own inherent resources, a controller will have to sort out the situation.

The desire to move from active control to less active supervision of system activity is by no means new, in many fields of activity. Similar shifts have already been noted on aircraft flight decks and also in many industrial applications. Problems with supervisory control tasks in such domains (most notably the “out of the loop” problem) are well-documented. The suggestion that an air traffic controller should become a “manager of exceptions”, however, appears not to have been advanced thus far. References to management by exception can be found in supervisory control studies, but searches for it reveal that these discussions are not deep and leave the concept underspecified.

It is important to examine closely what management by exception is, especially in terms of its implications for the cognitive work that a controller will have to do (in

collaboration with other system participants). What will the controller be looking for (supervising, monitoring)? When and how will he intervene? What qualifies as an exception? Answers to these questions are not just academic. They will have a direct bearing on how necessary rules and procedures for a more flexible future ATM environment, and on what kinds of interfaces are needed to ensure that controllers, as well as pilots, dispatchers and other system participants get the right information at the right time.

5.1.2 Overview of this chapter

The studies discussed in this chapter were intended to provide some initial answers to the kinds of questions laid out above. They were an attempt to reveal the kind of work that controllers, pilots and dispatchers must engage in to run a future air traffic system safely and efficiently on a "management by exception" basis. These studies were aimed specifically at identifying areas where there is early evidence of potential human performance problems as a result of certain design decisions.

Participants in the studies were controllers, pilots, dispatchers and traffic managers in today's air traffic environment. These expert practitioners were briefed on the rules and particulars of an envisioned air traffic management world and were subsequently confronted with concrete problems as they may occur in the future. The practitioners' differing perspectives on the problems and the environment generated discussion and revealed where problems may emerge with workload, information availability, communication, coordination and decision making.

Participants were exposed to future problem situations in a widely agreed upon vision of the future air traffic environment described by RTCA (1995) and called "free flight". Some practitioners actually entertained more extreme interpretations of what the future world will be like. The findings of these studies cover the envisioned world proposed by RTCA (1995), but the requirements that can be generated from this research may be considered in relation to other versions of the envisioned environment as well.

It appears that in management by exception a controller does not respond to anomalies per se, but needs to anticipate problems in how other agents (pilots, operators) are dealing with process anomalies. This requires him to make complex trade-off judgements that involve questions of *how many* aircraft to restrict in their flexibility, *how much* to restrict them, and *when* to intervene relative to the continuous emergence of evidence about impending problems. These trade-offs must be made under the time pressure of a potentially escalating situation, and within constraints that stem from considerations for safety, throughput, efficiency, economic interests of airlines, and empirical factors such as controller workload.

A characteristic of more flexible air traffic worlds appears to be a wider distribution of information, knowledge and decision-making authority among system participants. This feature, which also emerges from other studies reported in this

volume, points to a burden on developers to incorporate robust means of communication, and to be sensitive to the fact that information sharing is subject to attentional and workload constraints during periods of high system activity.

5.2 Management by exception

Although management by exception seems an intuitive concept that could be used to guide future system designs, there is neither a generally accepted definition of management by exception nor much specification of what it actually could be. The concept of management by exception was born out of the supervisory control paradigm in the mid- to late seventies (Sheridan, 1976). This paradigm, in which a manager supervises subordinate agents (mostly computers and other machines) in their execution of domain tasks, gave rise to the question what the relationship between a supervisor and subordinates could or should be.

With increasingly capable subordinate agents, one possibility for this relationship became based on the principle of exception. Wiener (1988, p. 456) explains this principle by stating that “as long as things are going well or according to plan, leave the managers alone. Don’t clutter their world with reports, warnings, and messages of normal conditions. ‘Exceptions’ are pre-defined and lower level managers flag exceptions, which are routed to the manager”. When exceptions are found, several things can happen (Sheridan, 1992). First, the subordinate could “allow the [manager] a restricted time to veto before automatic execution” of some resolution, or the subordinate “executes automatically and then informs the manager” (p. 358).

Many questions arise from these definitions. Who notices the exception, for example, and if it is the manager who notices, what is he in fact looking for? Does he monitor for actual process conditions, or does he merely observe his subordinates and judge how well they are dealing with the process? Is he waiting for specific occurrences before he intervenes, or is the recognition of what is an exception a more abstract judgement? And when intervention is deemed necessary, does the manager take full control, or are there ways in which he and subordinates can redistribute and share authority over the process?

These questions represent gaps in our current understanding of management by exception, and they form the motivation for the studies reported here. These studies have investigated the complexity that lies behind managing a future air traffic management system by exception; they have attempted to reveal some of the cognitive demands that are imposed on human managers who must anticipate problems in how other agents (human or machine) are handling a safety-critical process.

5.3 Method of investigation

5.3.1 Investigating cognition in an envisioned world

As noted in relation to other studies discussed in this report, and particularly in report no. 2 in this volume, management by exception in air traffic control does not yet exist. Investigating cognition in such an envisioned world is therefore a methodological challenge. There are no prototypes or system mock-ups, and no practitioners who work in the future world. Still, it is a tantalizing and potentially fruitful prospect to reveal some of the cognitive post-conditions of technological and procedural changes before large pools of resources are committed to particular designs. What are ways to detect new opportunities for error or other human performance problems in an envisioned environment?

The biggest problem inhibiting the investigation of a future world is its underspecification. Many details of the envisioned environment will not have been worked out yet or made concrete through system design. Furthermore, every participant or stakeholder is likely to have a different interpretation of what the future will look like and how the system will work. In order to begin the investigation of a future world, some kind of consensus must be found. In the case of air traffic control, the interpretation of RTCA (1995) represents the broadest agreement yet on what free flight will be. Many different constituencies (air traffic control, airlines, pilots, manufacturers, NASA, Navy, Air Force) participated in this initial definition of a future air traffic environment in the U.S.

5.3.2 Future incidents

The proposed rules, roles and technologies that together make up RTCA's version of the future world were confronted by hard constraints and problems that occur in the airspace environment, irrespective of which air traffic control technologies or rules are applied (e.g., weather problems or mechanical failures in aircraft). This marriage between future designs and timeless problems produced "future incident scenarios" that were put before expert practitioners (air traffic controllers, pilots, dispatchers and air traffic movements coordinators).

In order to cope with the underspecification of the future world, it was critical to simultaneously anchor different expert practitioners in the details of coordination, communication, decision making and knowledge exchange necessary to handle the incidents successfully (Smith et al., 1996). This encounter of multiple practitioner perspectives with concrete future problems exposed disjunctions in how the various groups (pilots, controllers) interpreted the problem. These disjoints were places where, for instance, practitioners' goals conflicted, or where information thought to be readily at hand was actually unavailable.

Rather than providing yet another potentially underspecified demonstration of how the future world might function, these incidents, and the disjoints in perspectives

they revealed, produced data about where a future architecture might be vulnerable or how it may break down. Thus, the incidents invited practitioners to think critically about the cognitive work and tools required for effective problem solving in the envisioned world.

In the studies reported here, participating practitioners were presented with future problem scenarios by way of a "cognitive walkthrough". Practitioners were first prepared for their future roles and rules by briefings and specially prepared handbook excerpts (see report no. 2 and Dekker, 1996). Then they were provided with the initial conditions of some situation, as represented on a "game board" -- a rendition of a radar screen on which participants could annotate (and leave a trace of) their suggestions for solutions. Thereafter, participants were left on their own, caught up in the evolving incident. The area in which the future incidents took place was a segment of airspace in the U.S. (see p. 2-15), modified to accommodate new free flight rules, that contained many interesting characteristics usable in the creation of incidents (thunderstorms, clear air turbulence, funneling flows of traffic into a few major airports, crossing traffic, etc.). The discussions were recorded on videotape and transcribed later.

5.4 Findings of the studies

5.4.1 Different participants: different goals

In a more flexible air traffic environment pilots may be able to pursue their company goals better than they can today (RTCA, 1995). These company goals can include timely arrivals, fuel savings, customer satisfaction, etc. Controllers, on the other hand, will continue to be concerned with overall system goals such as safety, efficiency and throughput, and adherence to regulations. Although the pursuit of these diverse goals may be efficient from one perspective, it can be problematic from another. For example, going for a different altitude because of more favorable winds is productive from a local company perspective. From the controller's perspective, however, this may jeopardize his system goal of safety if many aircraft will be doing the same thing. This is the basis for management by exception in free flight: controller and pilots have different goals and different perspectives on the problem or process (see also Guerlain & Smith, 1995).

Rather than handling process anomalies directly, the controller's focus is on responding to problems in how pilots are handling process anomalies. For example, a line of thunderstorms was presented as a system anomaly in one of the scenarios in this study. It turned out that the controller becomes involved not in reaction to this anomaly, but only when his system goals are jeopardized by the way in which other agents (pilots) are dealing with the anomaly. For instance, airplanes may start funneling for a hole in the line of thunderstorms, which may produce problems for separation and safety. This also indicates that problems (possible separation conflicts, in this example) in how pilots are handling process anomalies must often be anticipated rather than awaited. Management by exception, then, is concerned

with handling problems in how other agents are dealing with anomalies in the process. Note that this means that a process anomaly does not necessarily constitute an exception that requires management intervention.

5.4.2 Multiple trade-off judgements

Anticipating problems in how pilots are handling process anomalies can be demanding. It may be difficult for a controller to gather evidence on precisely how, and how effectively, pilots are handling the anomaly. The demands produced by this uncertainty were demonstrated in a scenario that involved an aircraft with malfunctioning communications and collision avoidance equipment¹. (Failed communications equipment is commonly referred to as “nordo”, for “no radio”). In this future incident scenario, a nordo aircraft was approaching a stream of traffic inbound for a major airport (as schematically represented in figure 5-1). The nordo aircraft itself was originally headed for its homebase, but after the failure its intentions became uncertain.

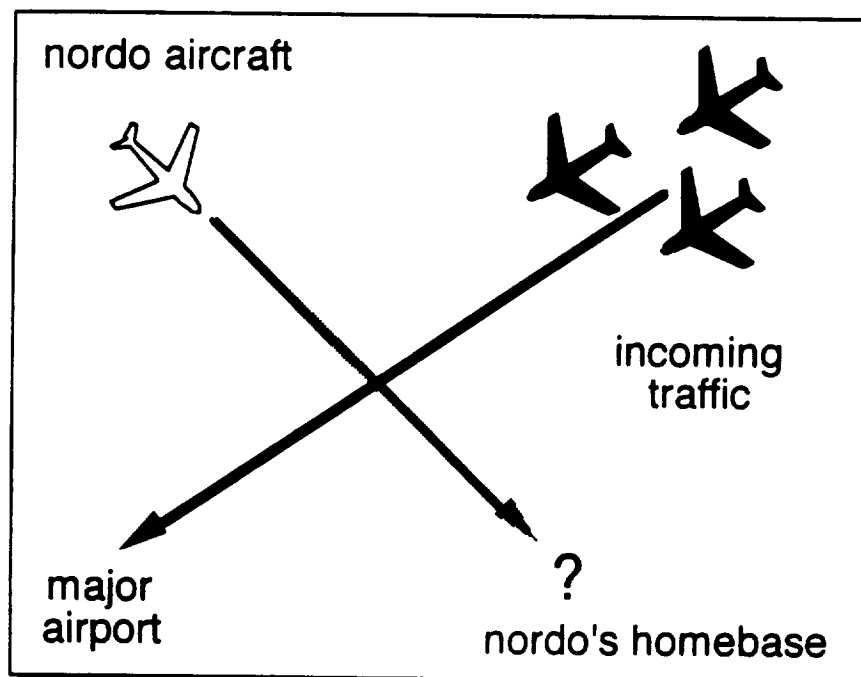


Figure 5-1: Schematic representation of the problem in one scenario

¹ The aircraft in this future incident scenario was transmitting code 7600 on Mode A of its transponder, indicating that it had suffered a communications failure. Transponding on Mode A indicates that Mode C and/or Mode S (crucial for today's on-board collision avoidance technology) may also be inoperative. This means that other aircraft interrogating this aircraft's

The ambiguity in the possible intentions of the nordo aircraft (is it going on to homebase for repairs, or is it going to land at the nearest suitable airport?) makes predicting how it will affect the stream of incoming traffic difficult. The controller does not know how pilots will deal with this anomaly in their process. Given this uncertainty, it turns out that in the controller faces three judgements in his decision to intervene: (1) the controller must decide *when* to intervene, (2) determine *how many* aircraft should be restricted in their flexibility, and (3) *how much* authority should be taken away from these aircraft.

In trying to deal with the problem of a nordo aircraft, air traffic controllers negotiated a number of paths through these three trade-offs. In figure 5-2 these solution traces are marked at their starting points by the numbers 1 through 3. Remarkably, controllers did not reach consensus on any of the paths. Rather, they discovered a series of dilemmas (see the boxes in figure 5-2) and finally arrived at the third option, where they actually left themselves no room for their higher-level system view on this problem. There, the solution trace literally strays off the chart. The three traces are discussed in detail below.

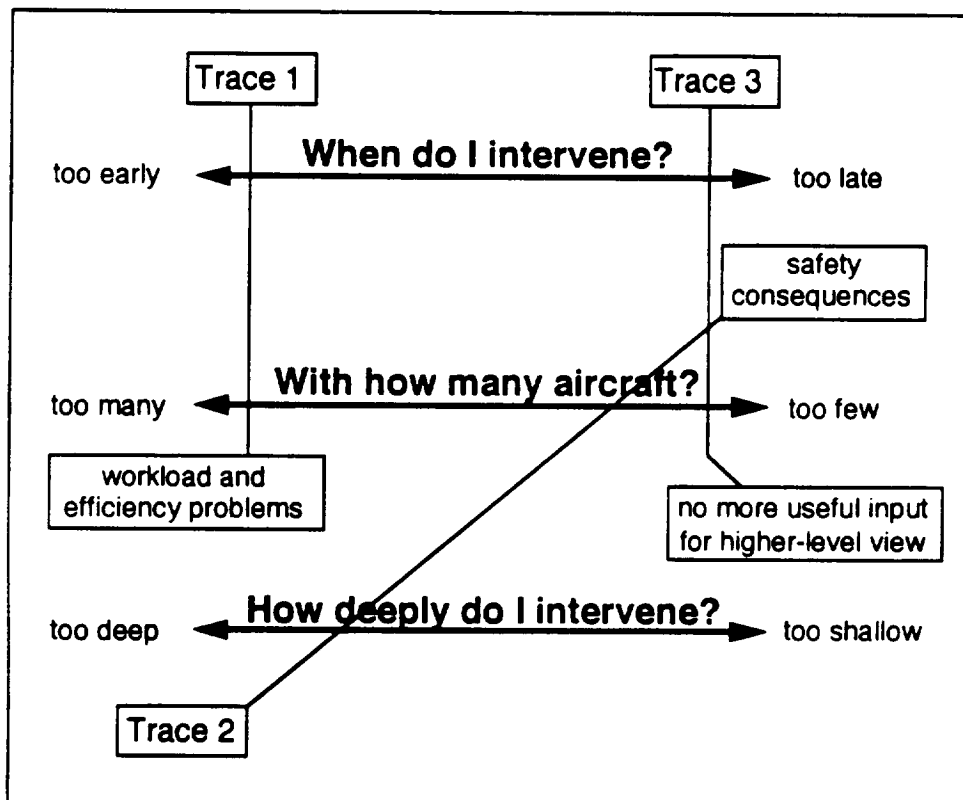


Figure 2: The three trade-offs faced by a controller: when to intervene; with how many airplanes, and how deeply. Traces 1-3 represent possible solutions (and outcome problems) that were explored by controllers.

transponder may see it on their collision avoidance display, but they will not know its altitude,

Solution Trace 1. One controller proposes to deal with the nordo problem by asking all incoming aircraft to state their intentions before doing anything. Thus he can anticipate where problems are going to arise early on:

- Controller 1: "I want everybody (referring to traffic east of OAL) to tell me before they do something."

But according to another controller, such an early intervention means talking to too many aircraft - which imposes unnecessary attentional demands on a controller:

- Controller 2: "But when I'm busy and I've got everybody and their brother either downlinking or yelling 'I'm climbing, I'm descending, I'm turning, I'm doing this, I'm doing that' - I could care less! Mind yourself, I'm going to take care of the imminent situation."

Solution Trace 2. The alternative is to take control only over the airplanes that are closest to a collision threat, what controller 2 calls the "imminent situation". Taking full control represents a deeper intervention:

- Controller 2: "The first two that I need to work on here are these two here. So I'm going to say, 'OK, sir, I'm going to ask you to set this puppy on its wing and turn in a second'."

This turns out to be problematic. Since no other aircraft is asked to do or say anything, too few aircraft are involved in this intervention to assure that it is going to work:

- Controller 3: "The missing thing here is that they [the other aircraft] don't need to fly a filed altitude, they can leave that altitude. I wouldn't turn anybody here; I think that would be a mistake."
- Controller 4: "Yes, by taking positive control you can make it a lot worse."

This seems to put controllers in a double bind. Intervening in the flight paths of only a few aircraft is deemed ineffective because it is not known (or controlled) what other aircraft in the vicinity will do. The alternative is to be informed about the flight paths of every aircraft in the area (as suggested in Trace 1) but this, let alone taking control over everyone, is judged to lead to workload problems.

Solution Trace 3. The third trace represents some kind of resolution to the double bind. It essentially marginalizes input from a controller in this case. Given the uncertainty about the nordo aircraft's intentions (and those of the surrounding

and their collision avoidance systems will be unable to issue them advisories for the resolution

traffic), holding off on an intervention may be the only way to see more evidence emerge on how the anomaly is developing. But by then it seems that nothing is left that a controller can usefully add to the situation from his broader systems perspective—in fact:

- Controller 1: “They [the other traffic] would have a better view of the nordo aircraft with their 40 mile range TCAS than we have.”
- Controller 3: “And the nordo aircraft’s fishfinder could still be picking up these guys here” (pointing to the other traffic).

The suggestion to leave the airplanes to their own devices is directly related to uncertainty and a lack of knowledge about how traffic is going to behave:

- Controller 4: “If you don’t know what [the nordo aircraft] is going to do, what *can* you do as a controller?”
- Controller 1: “Since we don’t have all the parameters, do we *have* to do anything?”

This last remark is left as question rather than as a resolution. The dilemma of how (and whether) to deal with the problem of a nordo aircraft reveals some of the complexity of management by exception. Cognitive demands arise as a product of having to make multiple trade-offs in a time-pressured and potentially deteriorating situation. How many aircraft must a controller restrict? How far must (s)he restrict them? When does (s)he ultimately take over control? The solution traces show that these trade-offs are not independent, but that they interact in ways that can put controllers in double binds. For instance, early intervention must involve many aircraft, because evidence about exactly which airplanes are going to be a problem has not yet emerged. Although such close involvement with the flight paths of many aircraft early in a developing anomaly may be the safest option, it clearly carries costs in terms of decreasing throughput and increasing workload.

5.4.3 The issue of intent

The most important missing thing in the above scenario is knowledge of intent. If only the controller knew everyone’s intentions, the situation would be easier to handle. Does this mean that the foremost system requirement should be that “the controller needs to know intent”? From the data, it seems not. Finding out what every aircraft’s intentions were was deemed to be demanding and perhaps costly to system efficiency. This means that the requirement that “the controller needs to know intent” is too coarse. It does not take into account that knowing individual aircraft intents can be impossible under the constraints and competing attentional demands of escalating problem situations; it ignores the fact that knowing every

airplane's individual intent is orthogonal to facilitating more throughput in the airspace, and finally, it may not capture how intent can be the product of complex interactions between aircraft that are recognized on the basis of prior exposure to similar situations.

Rather, the question of what or whose intent should be known or communicated, must be made context-sensitive. In particular cases, such as the nordo aircraft, it would be really helpful to know that airplane's individual intent; without knowing that, it may be less relevant and even intrusive to hear what all the surrounding traffic is doing. Walkthroughs of future incidents revealed that controllers face multiple trade-offs and must reconcile constraints that stem from many sources, such as safety, workload, throughput, and economic interests of a carrier. The requirement that intent be sensitive to the problem-solving context captures more of the variety of pressures and competing demands inherent to escalating situations.

Recommendation 1: Instead of defining a requirement "the controller needs to know intent", it needs to be explored how communication of intent can be made sensitive to the problem-solving context. Knowing and communicating intent in future airspace environments will be subject to various pressures (e.g. problem escalation; controller workload; efficiency).

The question, of course, is how to make the communication of intent sensitive to the problem-solving context. ATC is an expertise-intensive activity. Controllers seem to have little trouble defining the kinds of intent they need to know at particular moments during an evolving situation (i.e.: "do you see that traffic?" or "say indicated airspeed") and usually have no qualms about asking for it.

Another implication of the fact that intent may not be known (and this will be a characteristic of more flexible air traffic environments) is wider distribution of knowledge and information. Some participants have bits and pieces of knowledge necessary to solve a particular problem, and so do others. This emerged from the nordo aircraft scenario as well. Thus, future air traffic architectures must support the robust exchange of knowledge.

Recommendation 2: Given the wider distribution of knowledge, the importance of robust and context-sensitive communication channels must be acknowledged early in system development. In particular, it should be investigated what kinds of information flows between ATC to AOC are necessary to support the integration of two sets of goals (the arbitrator's (ATC) and the stakeholder's (AOC)) in determining an airplane's safest and most economical path.

Intent is not necessarily the reflection of quantifiable, or otherwise easily measured data (such as a final destination, or a particular altitude, or a velocity vector). Accordingly, the recognition of what requires intervention is not necessarily as simple as checking a single datum. Decision makers in natural contexts tend to let

their responses be driven by the recognition of patterns in their fields of activity (see Klein, 1993; Orasanu & Connolly, 1993). They recognize situations in terms of their relevant cues and typical actions (Klein, 1993). This simplifies the question of when (and what kind of) intervention is necessary: pattern recognition often triggers one response from a limited repertoire of strategies that have been well-rehearsed over years of operational experience (Sarter & Woods, 1992; 1994)

Various future problem-solving situations were presented to controllers; they contained different situations in which traffic started forming recognizable patterns. In one scenario, for instance, aircraft inbound for a major airport encountered a line of thunderstorms. Rather than judging or inquiring about movements of individual airplanes, controllers recognized the funneling of aircraft (in order to go through holes in the weather) as the pattern that gave rise to the need to intervene. This indicated that controllers may rely on the recognition of patterns in their operational world, and that they classify situations to ascertain the proper response to them:

- “a problem like this”
- “you’re basing it on a known situation”
- “in this scenario”
- “in this case”
- “we see this on a daily basis”

A typical way of responding to the thunderstorm case was to take control over the incoming waves of traffic and guide them through the holes one at a time, thus ensuring safe separation within waves while spreading the controller’s workload over time.

Another response that was examined in this research centered around a proposal by RTCA (1995) to take under control only those aircraft that presented the most pressing problem, and to ask surrounding traffic to circumvent the area or enter only after receiving a clearance. With this strategy, operators of surrounding aircraft can choose the best option based on their economic assessment. Thus this strategy has the potential to balance safety issues, an operator’s economic interests, and controller workload. Problems with this strategy arose in relation to flight crews, who must be made aware precisely what piece of airspace is under tighter control.

Recommendation 3: Explore the feasibility of dual strategies of control under more flexible air traffic management: i.e. taking only those aircraft under control that present the most pressing problem and asking surrounding traffic to circumvent the restricted area or enter it only after a receiving a clearance. Specifically, investigate:

- How boundaries of tighter controlled areas can be identified by controllers and communicated efficiently and unambiguously to flight crews (e.g. by portraying them on navigation displays with annotated altitude information)

- How dual strategies such as these can have a role at a more strategic (and pre-flight planning) level, when ATC indicates in advance which airspace areas are likely to be relatively restricted and which are not.

With initial evaluation of these dual strategies, problem solving strategies of practitioners suggested that they would rely on the recognition of frequently occurring traffic patterns to judge whether or not the RTCA strategy would work.

One of the implications of pattern recognition and reliance on prior experience is that a criterion for intervention (and the determination of what kind of intervention is necessary) is empirical, i.e., based in part on past exposure to similar situations. This may mean that decisions of when and how to intervene are, to a degree, subjective and that many different responses can fall within the same definition of "safe separation" under free flight rules, although what is actually permissible may well vary by controller, by day, by sector or by center (see recommendation 7).

If recognition-based anticipation of problems is indeed among the dominant strategies used in judging what situations require intervention, then it becomes crucial to examine how more flexible air traffic worlds might change the signature of air traffic behavior and whether this would aid or reduce a controller's ability to recognize patterns or particular types of situations "on a daily basis". Controllers express concern about this as follows:

- "In free flight, nothing is preset. You will have to scan all the time. In the current system there are confliction points where you expect flows to cross on a daily basis. You focus on confliction points. But in a free flight environment, everything is a focus point."

Similarly, initiatives toward adaptive resectorization (RTCA, 1995) in free flight must be evaluated in terms of their impact on how a controller can rely on prior experience to solve problems in his airspace. Increased diffusion of airplanes and changing sector boundaries could lead to surprises and novel situations that may defy a controller's earlier familiarity with problems in his or her sector.

Recommendation 4: Evaluate the extent to which more flexible air traffic management will affect the regularity of traffic flow patterns and the occurrence of typical, easily recognizable problems within particular sectors. Examine whether adaptive sector boundaries would present controllers with a larger number of novel problems.

Several issues related to the data gathered in the first study deserve some attention here. Practitioners were not provided with (informational) flight paths of all aircraft (whether these aircraft were relevant to the problem or not) as would actually be part of RTCA's (1996b) version of free flight. Also, it was not clear to controllers that

they will be informed whenever changes in such an informational flight plan take place. In these senses, controllers were led to assume a more extreme version of the future world than RTCA's (1995) proposal envisions. This means that there are several issues related to specific scenarios that may be worth examining further.

Recommendation 5: Conduct future incident studies with participants of various backgrounds (pilots, controllers, dispatchers, flow controllers) while exploring the following conditions:

- Participants are made aware in advance of the proposed RTCA rule that informational flight plans will be available and that these will be updated as soon as local agents make changes;
- Participants are provided with these more detailed flight plans of the airplanes that are in their sector in the scenario. What could be ways to provide this so that it resembles the practitioners' world, where they are caught up in time-paced, evolving operations?
- Under the above two conditions: an aircraft suffers a communication failure immediately or shortly after announcing a change to its flight plan (so the uncertainty about what it might do is re-inserted).

In examining these additional questions, it is important to understand that the data generated in the current study are neither high-level discussions (i.e., open-ended elicitations) nor true protocols from time-paced simulations, but that as reports or traces of problem-solving they fall somewhere in between. Practitioners were bound to a concrete problem-solving protocol, but not set in an event-driven simulation. This can be seen as a first step on the road toward meeting the challenge of investigating future worlds. The criterion at this point is that the interpretation, of what makes recognizing exceptions a difficult judgement, speaks to the data at hand. Furthermore, there are not many competing ideas (not even within the supervisory control literature) that discuss in detail the kind of distributed and cooperative problem-solving between cognitive agents that was encountered in the future world of free flight. For subsequent investigations of future system architectures, however, it is important that consideration be given to incorporating the event-driven nature and real-time deadlines typical of the domain of air traffic control.

Recommendation 6: Explore ways in which the event-driven and time-paced characteristics of the domain of air traffic control can be incorporated in further future incident studies.

5.4.4 The criteria for success and failure in the future system

The nordo scenario exposes the difficult question of what counts as over-intervention and what as under-intervention in management by exception, and

what counts as success and what as failure. As in the example above, does intervening early also mean over-intervention? It may be considered a success if an unsafe situation was avoided, but from an efficiency or throughput perspective such early intervention might represent a failure of the system to function well. The problem with early interventions is that they may tend to eradicate any evidence that an unsafe situation was indeed imminent: after having intervened it may be difficult to ascertain that an anomaly was actually developing and that the intervention was justified.

On the other hand, if a controller takes over only after an alert has been issued by an airborne collision avoidance device, this could be thought of as a late intervention. But is it also under-intervention? In other words, does the issuance of an alert mean that the system is functioning well and efficiently, and that no airplanes are unnecessarily interfered with? Or does it mean that the system is operating at the margins, closer to potential breakdown? Again, the answer may depend on one's perspective, but in this study both controllers and pilots expressed concern about late interventions:

- Controller: "By the time I get the alert, separation is already gone."
- Pilot: "You don't want to be in a position where you have to rely on your last line of defence, where you're ricocheting off each other."

Because of the nature of management by exception, the determination of when to intervene is subject to different pressures. Practitioners at the sharp end (controllers, pilots) have stakes in choosing the option that is likely to most benefit their safety. However, activities of these practitioners involve other sets of goals as well: system throughput (for controllers) and an airline company's economic interests (for pilots). Early (perhaps safer) interventions can jeopardize these goals. Restricting an aircraft's flexibility, for instance, can increase the uncertainty about what may happen to company goals such as timely arrivals or fuel savings.

Recommendation 7: The criteria for controller intervention appear to be formed on the basis of various considerations (safety, throughput, workload, empirical factors). There is need to investigate further what criteria for intervention will be emphasized in specific future air traffic environments and how these criteria are established as a result of operational experience.

5.4.5 System learning

The issues about setting a criterion for intervention and what counts as over- or underintervention raise another question. How does a management by exception system learn from its own performance? As explained earlier, the very act of intervening may destroy the opportunity to learn. Would an anomaly have developed if intervention was delayed or not initiated at all? There may be no way of concluding this from individual cases, so for the air traffic system to know how

well or poorly it is doing, it must be able to compare across multiple interventions. This requires some sort of system memory (and a mechanism for information sharing) that tracks the kinds and number of interventions (by sector, or center, or airline, etc.). The contents of such a memory will likely have to be measured against different criteria in order to arrive at indications of performance, such as airline economic interests on the one hand and separation standards on the other.

Recommendation 8: In order to learn from its own performance, relative to safety or economic targets, the air traffic system will require some kind of memory, so that multiple cases of interventions can be compared. Studies are needed to determine (1) what the precise contents of such a memory should be (e.g., Interventions per se? Only separation conflicts? Or all automatic conflict resolutions?), (2) against what yardstick the contents of such memory must be compared: e.g., safety or economic targets (but note the dichotomy of what counts as over- and underintervention, depending on the perspective one takes) and (3) how such a memory can be made organizationally feasible (given confidentiality issues, possible pressures not to report in cases of safety breaches, etc.).

5.4.6 Success and failure in cooperative, distributed systems

Free flight in general, and this research in particular, shows that when knowledge, authority, and points of view of an evolving problem are distributed across various participants in a system, a large burden is placed on the effectivity and robustness of mechanisms for sharing information. But effective sharing goes beyond providing robust channels: it must be sensitive to the fact that cognitive activities in dynamic systems ebb and flow as well, and that knowledge that is available somewhere in the system is not necessarily accessible elsewhere, given workload or other pressures. In many situations it is easy to observe that the most information sharing is necessary when workload and competition for attentional resources are already high.

It is important to note that in relation to these issues, we must shift our viewpoint from thinking of one practitioner as crucial to the success or failure of a system, to thinking of collaborative work as being critical to a distributed system's success. Conversely, failure in cooperative distributed systems is indeed that: a failure of the cooperative system to function effectively. There is much research to be done to enlarge our understanding of the causation and propagation of failure in cooperative distributed systems. Many failures in complex distributed systems are still attributed to a single "human error"; the failure of one practitioner to act in a certain way at a single moment during the incident evolution

Although these attributions may be consistent with empirical facts in a narrow sense, they assume that an individual action can be excised from its context to produce a meaningful explanation of a chain of events that unfolded under the hands of multiple agents, both human and machine. Such explanations cannot capture the important information hidden in these incidents: failures in complex,

distributed systems are often the outcome of a series of miscoordinations and miscommunications, where inaccurate or inadequate mental models of the situation on the part of individual participants are built and fostered through their interactions with other agents in the system. A typical failure, that can be expected in an architecture such as free flight, is that all the information necessary to solve a particular problem was available somewhere in the system, but distributed in such a way that it was inaccessible to practitioners caught up in the evolving incident, or distributed in a way that was not encountered previously. Some of this is demonstrated in the incident with the nordo aircraft.

Recommendation 9: Expand our understanding of success and failure in highly distributed, multi-agent systems, with an emphasis on the potential contribution of distributed information and/or knowledge (1) through retrospective investigations of incidents and accidents in various complex, distributed worlds, and (2) through examination of envisioned distributed system architectures by way of future incidents that pose challenges to the coordination and communication across multiple different system participants.

5.4.7 Responsibility in cooperative, distributed systems

If failures in complex system are a concatenation of multiple contributions, then who is responsible? It is commonly thought that if knowledge is distributed to an extent that *everybody* contributes to, and is partly responsible for, the propagation of a failure, then nobody really ends up being responsible. But this is inconsistent with findings from the future incident studies in this research. Distributed knowledge means distributed (in the sense of localized) responsibility:

- Controller: "If I'm responsible, there's the caveat that I need to know what's going on."

If controllers are to be responsible for separation, then they "need to know what's going on". In other words, no knowledge: no responsibility. This coupling of responsibility with knowledge is particularly interesting when the reverse question is asked. If there is knowledge, does responsibility automatically attach itself to it? Does responsibility travel with knowledge? Study participants pondered this question and found that they faced a dilemma. Controllers may not know how much or little another agent in the system knows; it is therefore uncertain how much authority should or can be delegated.

The case of the nordo aircraft serves as an illustration once more. The question is, what does the nordo aircraft know? Can its collision avoidance system see the altitudes of surrounding traffic and thus generate a resolution advisory to avoid separation conflicts? Much discussion on what the nordo aircraft would or would not see turns out to depend on the type of collision avoidance system that is on board - something that is not known to controllers. One participant concludes:

- Controller: "Okay, if we know that this guy [the nordo aircraft] can see the altitudes of other airplanes then I would be a little less worried about him. Now if I don't know this, I'd be a little bit ... nervous, to say the least."

Given enough time, there would be ways to find out how much the nordo aircraft knows (i.e., what type of collision avoidance system it has); controllers could contact the airline operations center, for instance. But this is unlikely to be feasible in the face of a rapidly deteriorating situation. Besides, there is no certainty that the crew of the nordo aircraft, even if equipped with the right system, has an opportunity to look at it, given the competing attentional demands brought on by multiple on-board malfunctions. As one pilot remarked:

- Pilot: "It's hard enough to fly the airplane, now you're going to make me control myself and half a dozen others too?"

The delegation of responsibility may thus be based on unsubstantiated assumptions about what other agents in the system know. This means that knowledge and responsibility are likely to become disjointed in certain cases, where one agent delegates responsibility on the basis of presuppositions about what the other agent knows, while the other agent actually lacks access to a critical piece of knowledge. The one agent can wait longer, as was shown earlier, to produce more evidence about what the other agent does or does not know about his situation. But this can lead to escalation and a loss of opportunities to recover from failure.

5.5 Concluding Remarks

Two main issues emerge from this study: (1) the complexity of management by exception and its implications for success and failure in highly distributed multi-agent architectures, and (2) the need for definition of system requirements early in the development cycle.

5.5.1 The complexity of management by exception

If we first go back to the questions asked about management by exception in the introduction, what contributions has this research made?

Who notices the exceptions? The manager does. Exceptions are cases in which (subordinate) agents handle process anomalies in such a way that they may jeopardize a manager's system goals of safety, efficiency or adherence to regulations. As seen in the scenario with thunderstorms, pilots may handle process anomalies in a way that is consistent with their company's goals (e.g., no delays). When this pursuit is combined with actions of other airplanes, however, it may threaten the manager's overall system goals, something a pilot with a more local perspective on the problem is unable to see.

What is the manager looking for? The manager is concerned with problems that may arise in how other agents are dealing with anomalies in their process. Management by exception is inherently about the future. In order to protect his goals of system safety and efficiency and adherence to regulations, the manager must anticipate how agents' behavior may lead to problems. By waiting too long (e.g. until automatic conflict resolutions have been issued to aircraft) a manager effectively excludes himself from helping to solve the problem. Since individual intentions may at times be hard to evaluate in a future, more autonomous air traffic world, it was conjectured how a manager might rely on the recognition of recurrent patterns in his environment. In one study, pattern recognition was shown to be able to help a manager identify situations that called for intervention and to drive the selection of a known, well-rehearsed response to deal with the problem.

What does a manager do to intervene? At first glance, it seems that a manager has many ways of intervening in how other agents are handling the process. He can wait for more evidence to emerge on exactly which agents will create the biggest problems; he can adjust the number of agents who are going to be affected by the intervention, and he can vary the extent to which he reins in their authority. But closer examination reveals that during an escalating anomaly the manager is rather constrained in what he can do. The three trade-offs he needs to make appear interconnected, and can end up putting him in double binds. Early intervention, for instance, may be a safe option to choose, but it carries costs in terms of lost throughput and high attentional demands. Intervening with fewer airplanes may turn out to be ineffective and potentially dangerous, since it may not be known (and is not controlled) what surrounding traffic will do. Finding out the intentions of surrounding traffic will again lead to competition for limited attentional resources. And the longer the manager waits with his intervention, so as to be positive about exactly who should be reined in, the less room and time he leaves himself to make a useful contribution to the problem with his higher-level system view.

What about success and failure in management by exception? The original idea in supervisory control that there is only one trade-off to make (intervening versus gathering more evidence) and only one way to intervene (all or nothing) oversimplifies matters. The trade-offs that a manager faces in management by exception appear far more complicated and multifaceted. For example, taking total control in the future free flight incidents was thought impossible due to workload and throughput pressures. Success or failure in these kinds of systems is no longer a matter of intervening in time or not. Succeeding is striking a delicate balance between multiple trade-offs (how many aircraft; when; how deep an intervention?) and reconciling a variety of pressures (safety, workload, throughput, economic concerns of individual operators, etc.). And whether the outcome of an intervention decision is deemed success or failure will ultimately depend on the perspective that is taken.

5.5.2 Early derivation of human factors requirements

This research aimed at evaluating the consequences of changes in technology and people's roles before large pools of resources were committed to particular system designs. By wedding timeless problems and constraints of the airspace environment with proposed procedures and envisioned technologies, future incidents were created. Together, these incidents constitute one method by which to quickly prototype and study how people and technology will coordinate in realistic operational scenarios for an envisioned air traffic management world (Smith et al., 1996). The fact that system design is still underspecified during the early stages of development is accompanied by the potential to oversimplify the impact of design decisions on practitioners' roles and activities. This oversimplification was countered by the confrontation of multiple practitioner perspectives during the incident walkthroughs. In this way, the looseness in understanding of how future worlds are going to work is anchored in the details of coordination necessary to handle a concrete incident scenario.

Thus, future incidents helped the early derivation of human factors requirements. For instance, through the cognitive walkthroughs of the nordo aircraft incident, it was possible to refine the requirement that "the controller needs to know intent". It was concluded that it is more meaningful to think about requirements of how to make the communication of intent context-sensitive. That is, how can designers ensure that intent is communicated in a fashion that is sensitive to the variety of pressures inherent to escalating problem scenarios? This example illustrates the worth of the use of these kinds of methods early in system development.

Recommendation 10: Efforts should be continued to explore and refine methods that can identify human performance problems very early in system development, and that can generate meaningful human factors requirements without large investments in prototypes or other resource commitments.

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HUMAN-CENTERED TECHNOLOGIES AND PROCEDURES FOR FUTURE AIR TRAFFIC MANAGEMENT

6. FACTORS INFLUENCING CONTROLLER PERFORMANCE: IMPLICATIONS FOR A FREE FLIGHT ENVIRONMENT

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6.1 Introduction

As a result of a series of knowledge elicitation studies, it became clear that a central question in the design of an environment to support free flight during the enroute portion of a flight is a clear definition of what information will be required to make air traffic control decisions and an understanding of how that information is used. The answers to this question have major implications for the design of computer systems to assist with the detection and resolution of potential conflicts, for the identification of the information that must be communicated between pilots and controllers when pilots have assumed responsibility for maintaining separation, for the design of rules and procedures, and for the assignment of roles to flight crews, controllers and technology.

6.2 Methods

We conducted a series of structured interviews at an Enroute Center to explore this topic in more detail. Two site visits were made to an Enroute Center, where six controllers were interviewed.

The following questions were used as the basis for structured interviews with controllers. (These interactions were tape recorded for later analysis.) The interviews were conducted on two separate occasions, based on the questions listed below.

6.2.1 First Interview

Issue 1. It has been suggested that the expanded NRP is causing reduced capacity at some choke points because the increased complexity requires greater separation distances:

- Question: If you are aware of such problems, are the increased separations due to an increased workload on the controller? If so, what factors contribute to this complexity?
- Question: Could the problem be overcome by increasing the number of controllers, by dynamic sectorization, or by support technologies?
- Question: What if we use technology to deal with this complexity in order to allow reduced separation and a situation arises that the technology can't detect or deal with?
- Question: What implications would allowing enroute free flight have regarding the concerns raised by Issue 1?
- Question: Could the concerns raised above lead to gridlocking a sector? What is the price paid when this happens?

Issue 2. What are the factors that an agent (human or computer) must consider in deciding whether a route or altitude change is acceptable?

- Question: How do the following factors influence such decisions
 - a. Positional uncertainty
 - a. Weather
 - b. Response times
 - c. Knowledge of intent
 - d. Traffic density and complexity
 - e. Predictability of traffic patterns
 - f. Availability of contingency plans

6.2.2 Second Interview

6.2.2.1 Weather Issues

- Question: What kinds of information do you have available to you about weather?
- Question: Can you give me specific examples of situations where weather was reported by one pilot and how you then handled other flights in the same area based on that pilot report?

- Question: Can you give me specific examples of how, after watching weather develop, you began predicting how other flights would be affected by it? In such situations, what contingency plans do you have to think about?
- Question: What are the implications for information exchange in these situations?

6.2.2.2 Knowledge of Intent

- Question: Can you give me examples of cases where there is a great deal of uncertainty about what a pilot will actually do in the near future (due, for example, to uncertainty about an immediate weather problem)?
- Question: When pilots are flying around a storm, how detailed is your knowledge of the path they will actually fly?

6.2.2.3 Traffic Complexity

- Question: Can you give me examples where the amount of traffic increases complexity?
- Question: Can you give me examples where the predictability of confliction points (both where and when) affects complexity?
- Question: Can you give me examples where you can recognize/categorize the situation and have preplanned solutions, such as using holding patterns, to deal with the situation?
- Question: Can you give me examples where the mix of aircraft increases complexity?
- Question: Can you give me examples where the experience and skill of the controller influences his or her ability to deal with complexity?
- Question: Can you give me examples where the communications workload increases complexity?

6.2.2.4 Positional Uncertainty

- Question: Can you give me current world examples of positional uncertainty such as navigational error, measurement error, display accuracy?
- Question: Can you give me examples of positional uncertainty that could still arise in a future world with GPS and other advanced technologies?

6.2.2.5 Planning for Contingencies

- Question: Can you give me examples where you explicitly plan for contingencies when you believe a situation could become critical?
- Question: What are the implications for communications?

6.3 Subjects

Six controllers were included in the structured interviews. Demographic data on these controllers are shown below.

Controller #1: Years as a controller: 15

Pilot: flight instructor, commercial pilot with 2000 hours of experience

Other aviation jobs: flight center manager

College: three years of study at Embry-Riddle Aeronautical University

Controller #2: Years as a controller: 11

Pilot: no

Other aviation jobs: no

College: no

Controller #3: Years as a controller: 15 years

Pilot: no

Other aviation jobs: Air defense operator while serving in the Air Force

College: no

Controller #4: Years as a controller: 14 years

Other aviation jobs: no

College: no

Other jobs: Worked as an emergency medical technician for six years

Controller #5: Years as a controller: 18 years

Pilot: yes, with single engine aircraft rating

Other aviation jobs: first line supervisor, area manager, assistant manager for airspace and procedures, manager for procedures and automation

College: no

Other jobs: military experience with radar and electronics maintenance

Controller #6: Years as a controller: 28 years

Pilot: yes; ATP, flight instructor, single/ multi engine and instrument, helicopter and glider, commercial privileges, single engine land and sea

Other aviation jobs: first line supervisor

College: degree in business

6.4 Results and Discussion

The findings from this data collection effort are categorized below in terms of the types of knowledge and information necessary for controllers to effectively complete their tasks, and in terms of the implications of these requirements for developing an effective enroute free flight environment.

6.4.1 Factors Influencing Decision Making

Five factors were identified as important in making decisions to ensure safe routing and separation of aircraft. Each factor is described below, with examples indicating its significance for the design of an enroute free flight environment.

6.4.1.1 Weather Avoidance

Weather, in part, determines which alternatives are acceptable for amending a flight plan. At present, access to this information is distributed between the controller and the flight crew, and both must contribute their information when making a decision. According to the information gained from our interviews, the controller has access to five different types of information about weather. They include:

- Weather displays on radar screens (local weather);
- Verbal pilot reports;
- Weather monitors (displays with National Weather Service broadcasts);
- Teletype weather reports;
- Pilot reports (PIREPs).

Weather Displays: Weather can be displayed on the same radar scopes used to track aircraft. The precipitation which is shown is medium to high in intensity due to the fact that it comes from digitized radar. These weather displays deal only with airborne precipitation, and may be inaccurate as sometimes heavy moisture in the air can be displayed as precipitation. They do not show weather cells and sometimes miss precipitation. Further, that precipitation must be of at least a minimum intensity to be displayed due to the digital nature of the information. The weather radar is different from the radar which shows the position of airplanes, but uses the same system. This type of information does allow the controllers to build a mental picture of the weather situation. This mental picture is, however, incomplete, as one controller reported:

- "We sketch in our minds where the real storm is at [sic], but it constantly moves, it grows, it dissipates, so we rely on pilots to tell us where they go to avoid it."

Verbal Pilot Reports: As suggested in the quote above, much real time information about weather is relayed via verbal communication with pilots who have just flown through or around the weather in question. Controllers often solicit verbal

pilot reports to confirm the weather situation. Conversely, pilots sometimes request weather information from controllers. To gather this information, the controllers:

- “Ask another pilot who has just been through that area what’s there. We also ask what’s developing so we can predict what’s happening.”

Weather Monitors: This information is relayed via the National Weather Service. There is one weather monitor per geographical area, and this information is gathered by radar. Typically, the jet routes are not projected on this weather display, so controllers:

- “Put them on in your mind. Sometimes you can put jet routes on but it gets cluttered. A zoom feature exists, but when you are busy you can’t get to it. We use it for general observation only. And we can’t always view it from our scopes.”

Teletype Weather: The FAA service sends weather information to enroute centers on a regular basis. The weather information contained in these teletypes is in text format.

Pilot Reports (PIREPs): If a pilot experiences significant weather and believes that other pilots should be aware of it, he or she may file a PIREP. A PIREP is an official weather report which is then broadcast via the center’s service to the affected area. PIREPs are often the only source of information about certain weather phenomena such as clear air turbulence.

Use of Weather Data: These weather reports from different sources are important information for controllers and help them predict how traffic patterns will be affected by the weather. To deal with this weather data, the controller tries to take advantage of his or her past experience to anticipate the likely time course of the weather disturbance, and to select appropriate solutions for rerouting aircraft. As an example:

- “We can determine if a cell groups and blocks off an airway. We have to start rerouting airplanes so they don’t get to it. When we do that we put more miles-in-trail restrictions to have fewer planes. We can ask for a ground delay if they’re not airborne or give larger deviations if they’re enroute or on a delay vector. Airborne holding is avoided in this scenario. The closer you get to a terminal area, the more you use holding. Given where the weather is, if it’s right over New York, then we would hold here in our [Cleveland] Center until the weather passes. If weather is in between [the airplane and its destination] we try to get them around it. The direction of the flight is a big factor. If they [the aircraft] are going West, then you don’t want to hold [them], as the weather will pass through them. If [it’s] going East, we let the weather pass the airport and then we go in.”

Similarly, the distance of a flight from its destination affects how the controller handles that flight in adverse weather:

- “Another problem is winter storms. What do you do if a runway closes or a plane goes off a runway? That’s where you use your holding now. Airports try to give us a heads up time, if possible, for plowing the airports, but the agency doesn’t make the call on runway closings. You go into holding status throughout. If planes are on the ground, you keep them there. The increased workload and traffic volume depends on where the planes are at. If they are close to their destination, you put them in the stack and pull them out when you can. There may be major complications though. There may be icing when trying to hold or deviate. You may be able to take them higher to get out of an icing condition, but the decision to divert is an economic one and it stays with the user. We only make suggestions. A similar situation could occur if an ILS fails at the last minute, if an approach loses its radar, or if the weather is marginal.”

Past experience does not always, however, give the controller enough insights about how the weather will develop to make use of preplanned “canned” solutions:

- “Each context is different when it comes to weather. It depends on the severity, the height, the length. For instance, if it’s a couple of hundred miles, they’ll go around it. If it’s 800 miles, you pick your way through it and then it is a bumpy ride.”

An illustration of this:

- “is the O’Hare inbound push from the Northeast. If there’s weather everywhere and everyone is deviating, we’re trying to get 15 miles-in-trail and the planes down to 31,000 feet going into Chicago. Meanwhile O’Hare departures eastbound are supposed to be 60 to 80 miles south of the arrival traffic but are deviating into the inbound traffic to the north—into a sector that [usually] never sees them. That controller has no information as they are deviating too quickly. The traffic is climbing and descending head on at two Center boundaries. This happens one to two dozen times a year, anytime you have thunderstorms in the Midwest in the heart of the afternoon traffic. It’s the heaviest traffic period due to the flight times. There’s no canned solution as it’s too complex. We may use swap routes --take departing traffic way north, but we can’t do that when thunderstorms are there.”

A similar challenge arises because pilots differ in their assessments of risk:

- “When we’ve got an area of weather, whoever is number one does it first. Some will follow, others won’t. We just let them pick and choose what they want.”

Finally, there is an interesting example of cooperation. When confronted with storm activity, pilots do not necessarily precisely report their course change:

- “As for decisions to get them back on path, they let us know when they are clear of it and then they get back on their path.”

This strategy works in areas with low traffic density. However:

- “It is a problem if everyone deviates and then tries to go direct to get back on path. You have to have some semblance of order, especially if the aircraft are coming into the terminal area. There you need more structure than enroute.”

Finally, weather may have strategic implications. Although the weather in a particular sector may be fine, weather further along the intended flight path (as well as other problems such as airport restrictions) can have implications for decisions about how to amend a flight plan:

- “We start making decisions when we see weather build. We decide how close we let them get to it. Planes leaving California for New York with thunderstorms in Ohio—we would reroute them when in the Midwest, maybe taking them through a south routing.”

Implications of Weather Considerations for Designing Procedures and Technologies: The RTCA (1995) report on Free Flight proposes that controllers be allowed to delegate separation authority to a flight crew when the situation permits. Under such enroute free flight conditions, the flight crew then has the responsibility to ensure safe separation, with the controller acting as a safety net (monitoring the situation and intervening as necessary). There is also an assumption that technology will play a role in such a system, monitoring for potential conflicts. In essence, this scenario implies that pilots flying under free flight rules must take on the role of the controller. The discussion above about the use of weather data by controllers has important implications for this scenario.

First, the flight deck will have to have access to all of the pertinent data (weather and traffic) in a timely fashion, with an adequate field of view. Second, since in the foreseeable future technology cannot be expected to reason adequately about the potential impact of weather on conflicts, the flight crew will have to take over this responsibility from the controller. This means that the flight crew will have to reason about uncertainty in the weather and about how other flights will deal with the weather, and will have to plan contingencies for various possible occurrences. With regard to weather considerations, technology can at best provide decision support. The flight crew would have to integrate weather considerations into their final decisions. For example, if a number of flights was approaching a gap in a storm, intending to shoot through it, each crew would have to consider how they

would deal with the situation if the gap closed or if one or more of the other flight crews decided they did not want to continue through the gap.

Alternatively, the concept proposed by the RTCA report to restrict enroute free flight when the volume and complexity of traffic is too high could be extended to weather situations. In short, to reduce the complexity of the flight crew's task and to take advantage of the expertise that controllers have about the development of weather situations in their sectors, free flight could similarly be restricted in areas experiencing complex weather phenomena.

6.4.1.2 Knowledge of Intent

There are three cases that must be considered regarding the communication of intent. The first is when a flight plan entered into an FMS is being flown. In this case the intent can be communicated by that flight's computer to another computer or another person (though this is not done at present). A second case is when the plane is being "hand flown" by the pilot. His or her intent may be communicated verbally at an abstract level ("I'm going to pass around the storm to the south"), but the exact path is not known to the controller.

- "When a plane goes around a cloud his intent is known, but his true path is not known."

The third case occurs when a flight plan entered into an FMS is being followed, but it has not been updated to reflect a soon-to-be-necessary deviation (around a storm, to avoid traffic, etc.):

- "I'm going to change his route to avoid a storm, to accommodate other traffic. Or, if an airport is closed, he's going to have to hold or divert."

In such cases, the flight crew may have the information necessary to understand the implications of a developing situation well before any change of intent is reflected in the flight plan in a form that a computer can process. This can be problematic in terms of coordination in a free flight environment:

- "To have the big picture you need to know intent. Not knowing where the path will be can be a problem. If I change your path and another plane turns quickly, then we're back into trouble."

Implications of Knowledge and Intent for Roles and Responsibilities: As with the discussion regarding weather phenomena, it is clear that this analysis regarding the communication of intent implies that there will be situations where the FMS system will not adequately communicate the likely path of a flight, either because the flight crew is hand flying the plane around a storm or because there is some upcoming disturbance that may require a route change, but that change has not yet been entered into the FMS. The net result is that, if the flight is flying under

enroute free flight rules, the conflict detection technology will have to be treated as only one source of data for the flight crew, who will have to access and integrate all of the available data, as controllers currently do.

As with the discussion of weather above, an alternative is again to limit conditions where enroute free flight is allowed. For instance, one approach would be to suspend free flight anytime a flight deviates from its FMS programmed route, or where a complex situation exists in which significant short-term changes in route or altitude are possible.

6.4.1.3 Knowledge of Traffic Density and Complexity

There are many factors that influence the complexity of a traffic situation. Whatever agent is responsible for making decisions about a flight amendment (pilot, controller, or computer) must consider the impact of any decision on the complexity of the situation at that point in time or further along the flight path. It is clear that complexity is a complicated construct:

- "Complexity always varies with the number of aircraft. There's a minimum service time per aircraft: The frequency of communication -- you've got to check 'em off and on [establish initial contact and hand them off to the next controller]. There's a set evaluation time, a set minimum time to evaluate for potential conflicts. There's a minimum scan time on every airplane and minimum mental time for each plane. Complexity is that times the number of aircraft. That makes a maximum number of planes you can handle."
- "Speed variations among aircraft will make this more complicated. For example, when you try to do in trail [separation] with an MD-11 and an MD-80. the MD-80 is a lot slower, but you don't have room to let the fast one go by and you have to keep miles in trail."

Complexity is also affected by the ability to predict where confliction points will occur:

- "In the future, free flight will increase the service time, as nothing is preset. You will have to scan all the time. Confliction points are based on known intent and regular patterns of behavior. They are where flows cross on a daily basis. They are the only spots you concern yourself with. You focus on confliction points, but in a free flight environment, everything will have to be a focus point."

Complexity is also influenced by such knowledge of confliction points, as the controllers can often make use of pre-planned strategies for handling particular routine patterns of activity:

- “Six out of 10 times you do the same thing for conflict points. You’ve got two converging airways that go into one and you’ve got to put planes in trail and you know if you turn one line 30 degrees, then they fall in 10 miles in trail. Or instead of turning, you reduce and/or increase the speed of the other line, and then the converging lines of planes are put in trail.”

Implications for Flight Crews and Controllers: Traffic complexity issues in a free flight environment pose interesting challenges. First, if we accept the claim above that controllers successfully deal with complex traffic because there is predictability, then:

1. System designers need to be concerned with how a potential decrease in predictability under enroute free flight will be dealt with by controllers;
2. Flight crews presumably will need some technological substitute for the knowledge that individual controllers currently possess regarding conflict points and rule-based strategies for dealing with recurring situations within their particular sectors, as individual pilots cannot be expected to have sufficient experience with such patterns in specific sectors.

As with the previous discussions regarding weather and knowledge of intent, the alternative is to restrict free flight wherever the situation is expected to become complex enough to raise concerns. (This is consistent with the concept of “dynamic density” in the RTCA report.)

6.4.1.4 Planning for Contingencies

One controller discussed how the development of contingency plans are an integral part of his work: “99.5% of the time you have contingency plans.”

As an example, another controller reported that, if he knew there was a single hole in a storm front through which he would have to move a line of air traffic, he would do the following:

- “The smart controller will opt for altitude separation. I can’t control where they will have to fly in this situation, so I separate them by altitude. No one is at the same altitude. A controller also has to have Plan B in case a pilot refuses a directive. If more than four or five planes abreast are going for one hole, then I haven’t done good pre-planning. If I run into further problems, I try turning the following aircraft back 20 degrees or 90 or 180 degrees to avoid a conflict. This helps in addition to moving the planes in a “line” to different altitudes in case someone backs out.”

Implications of the Need for Contingency Planning: If enroute free flight is allowed in situations where significant contingency planning is required, then the flight

crews will have to somehow coordinate with each other (perhaps with the mediation of a controller) to ensure that suitable contingencies are available.

6.5 Conclusion

The points raised in these interviews make it clear that the job of the controller is a challenging one that requires a variety of reasoning about diverse situations. Much of the communication, whether about intent or contingencies, at present is not in a form which is easily input to a computer. Furthermore, while the ability to recognize typical situations helps the controller to recognize when he or she can use solutions which have proved reliable in the past, the complexity of the work requires constant evaluation by the controller to ascertain whether the current situation is sufficiently analogous to previous ones to know whether a pre-planned solution is appropriate.

The implication of this analysis of a controller's job is that, if enroute free flight is to be allowed, then either:

1. Flight crews will have to take on many of the challenging aspects of a controller's job while they are in free flight, requiring them to:
 - a. Have access to all pertinent weather and intent information currently available to controllers, in voice and/or digital form;
 - b. Develop the knowledge about particular sectors necessary to recognize and efficiently resolve conflicts;
 - c. Communicate and coordinate with other flight crews and controllers when implementing flight path amendments.

Because many important considerations will not be accessible to the computer, technology will at most provide a source of information that flight crews must then integrate in order to make decisions.

2. Alternatively, the RTCA concept of restricting free flight based on dynamic density will have to be refined to include consideration of factors such as weather, knowledge of intent and contingency planning. One implication of this is that controllers and traffic managers will have to have effective tools for dynamically defining regions where free flight is restricted temporarily, and methods for communicating these regions to flight crews and AOCs.

HUMAN-CENTERED TECHNOLOGIES AND PROCEDURES FOR FUTURE AIR TRAFFIC MANAGEMENT

7. HUMAN FACTORS ISSUES IN COMMUNICATION AND COORDINATION: PRACTICE-CENTERED PROCEDURES AND TECHNOLOGIES IN SUPPORT OF EFFECTIVE AIR-GROUND COORDINATION IN FUTURE ATM OPERATIONS

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7.1 Introduction

In some proposals for a future ATM system, pilots are assumed to have the option to dynamically adjust their flight path in response to a variety of factors such as changing environmental or aircraft conditions or to comply with company requests (RTCA, 1995). They will be able to do so without the need for approval from the ground. Notification of ground personnel of pilot-initiated actions may be recommended or required but there is no agreement yet concerning the timing of those notifications. As discussed by Billings (1996), some groups propose that "position and short-term intent information is provided to the air traffic service provider" (RTCA, 1995). Others, however, suggest that "subsequent to any change, a revised plan will be data-linked to the ground system for planning purposes" (IATA, 1994).

In other words, information on pilot-initiated actions may be available to ground-based operators only concurrently (as aircraft behavior is observed on the scope) or after-the-fact (once notified by the pilot). As a result, the likelihood of sudden unpredictable changes in traffic configurations and the need for immediate yet coordinated intervention in ongoing operations can be expected to increase for both pilots and controllers who are expected to share responsibilities for critical tasks such as aircraft separation. To support both pilots and ground-based operators in this highly dynamic, reactive approach to traffic management, practice- or use-centered communication technologies and procedures need to be developed that match the strategies, abilities, and needs of humans and machines and that take into consideration the various demands associated with different task contexts. Efficient

air-ground communication needs to be supported by these systems in the interest of aiding the rapid creation and updating of shared frames of reference among all participants in the air traffic system.

As a first step in the design of practice-centered systems and procedures, the purpose of and the demands associated with communication in future air traffic operations need to be identified and analyzed. Currently proposed system interfaces and protocols for digital and voice communication in the future ATM environment need to be examined in terms of their ability to effectively support those objectives and demands. First steps towards these goals were taken in the context of this project by means of conceptual walkthroughs involving pilots, controllers, and dispatchers. These groups served to simulate future air traffic management operations, especially in the context of highly dynamic high-tempo situations such as the transition from Free Flight to a more controlled environment or the need for immediate action for collision or obstacle avoidance.

These situations were chosen in part because they impose particularly high demands with respect to timely and efficient air-ground communication and coordination. Participants in these focus groups were asked to play out their likely roles in the future ATM environment to identify potential problems and to discuss possible solutions. This report discusses the communication-related issues that were raised in the context of those sessions. It also reviews the literature on experiences with currently proposed interfaces and protocols for digital communication and discusses their implications for future air traffic management operations.

7.2 The Purpose and Demands of Communication in Current and Future Air Traffic Environments

In the current ATC environment, the role of communication can best be described as a process of continuous mutual creation and recognition of commitments to actions (Austin, 1962; Winograd and Flores, 1986). Controllers play a fairly active role in communication in the sense that they initiate most contacts to issue clearances to aircraft under their control. These clearances have to be acknowledged and complied with by the crew. In turn, pilots can rely on controllers to ensure aircraft separation by indicating required actions or maneuvers for conflict resolution to them unless and until responsibility for this task is explicitly shifted from the ground to the flight deck. To maintain predictability and to support long-term planning of air traffic operations, pilots in the current environment can not change their flight path without approval from the ground, except in an emergency situation.

In contrast, some visions for future ATM operations do not call for firm commitments to actions. While long-term flight plans will likely be provided to the ground-based operator, pilots may be allowed to dynamically change their flight path at any time without approval from or coordination with the ground. Routine

communication will, in most cases, be initiated by the flight crew with the goal of providing the ground-based operator with information on pilot-initiated actions at the time of or immediately after-the-fact. Controllers are expected to communicate with flight crews primarily to resolve emerging conflicts or to respond to pilot requests.

In the current system, mutual cognitive environments and shared knowledge are established and continuously updated. What has been said by a pilot or controller is assumed to be known by the other person and is built upon in future exchanges (Krauss and Fussell, 1990; Clark and Brennan, 1991). This allows air traffic controllers to determine and anticipate the behavior of aircraft under their control and to issue conditional clearances which are based on earlier agreed-upon commitments by other aircraft. In a time-critical situation that requires controller intervention, the controller already possesses the relevant knowledge that is necessary to develop and implement a solution to the given problem.

In contrast, in the future air traffic environment, controllers may have to first gather information on everybody's status, activities, and intent before they can start working the observed or anticipated problem. Additional verbal explanations or reformulations in the interest of ensuring mutual understanding and grounding are known to be costly in time-constrained situations (Bressolle et al., 1995) but may become necessary in the future. This can be expected to affect the efficiency of operations and was a major area of concern to participants in our focus groups, as illustrated by the following quotes:

- "Today I could solve that [a traffic conflict] with one transmission. Now it might require six transmissions before I could even begin to solve it, because there's no sense in me laying out clearances if all these other guys who are doing Free Flight are going to start cranking and banking without telling me or as they are telling me."
- Controller A: "How am I supposed to separate him from those airplanes when I don't know what he's doing. I want everybody to tell me before they are doing something." Controller B: "But that's not Free Flight." Controller A: "I know that."
- "I can't very well give these guys an instruction based on what I hope the other guy is doing."

As illustrated by these quotes, participating controllers consider knowledge of intent to still be critical in future air traffic management operations. While they are willing to give up continuous active control of aircraft in their sector, they still want to be informed about the plans and activities of pilots in a timely manner. This is in line with the observation that "for agents to intentionally cooperate for their mutual benefit, they must have some common knowledge so that they can anticipate each other's actions and plan cooperative interactions. Cooperating

problem solvers, for example, can share high-level goals to improve the chances that they will cooperate effectively." (Durfee et al., 1990).

7.3 Proposed Communication Channels and Technologies for Future ATM Operations.

The primary medium for communication in future air traffic operations is expected to be Data Link, a two-way digital communication system that is currently under development. Some views of the future suggest that voice communication will still be available but will be considered a backup option to be used only in case of Data Link failures or to accommodate aircraft that are not equipped with the Data Link system.

Most participants in our studies did not agree that the voice channel should become a back-up option in the future. For them, voice communication will still be the medium of choice for communicating clearances or requests that require immediate action and compliance. Such clearances may well turn out to represent the majority of messages sent by controllers, given that their role in future ATM operations will primarily be exception handling rather than control of routine operations.

Participants in this project also cautioned that voice communication involves a number of benefits that would be lost with the introduction and significant use of digital communication. For example, with voice communication, information is not only shared by those immediately and directly affected by it but also by others on the same voice frequency. This allows them to anticipate and prepare for likely future clearances and actions (the so-called "party-line effect"). On modern automated aircraft, for example, this ability to anticipate clearances or problems allows pilots to preprogram their onboard systems ahead of time. In other words, the information that is shared on the voice channel helps them better distribute and balance their workload over time.

Concerns were voiced not only about the potential loss of voice communication but also about a potential mismatch between future ATM operations and currently proposed protocols and interfaces for digital communication. Data Link, the envisioned digital communication system of the future, was originally developed to address existing problems with voice communication such as frequency congestion, call sign confusion, or poor transmission quality (Kerns, 1994). Its design seems to be driven primarily by the demands and properties of the current air traffic control system. It is therefore not clear that the resulting system design will also be as adequate for handling communication and coordination in future ATM operations.

Some mismatches can be anticipated based on findings from simulation studies of two-way Data Link communication (for an overview see Kerns, 1994). These findings, while established in the context of simulations of current air traffic operations, have implications for future air traffic management as well. For example, a number of studies looked at the amount of time or the number of

transmissions required to complete a communication when using Data Link versus voice communication. It was shown that total transaction time (i.e., entire time span when a controller would be concerned with a given communication) was twice as long for Data Link as for voice. This can be explained by various factors such as the possibility of delayed responses to DL messages or by more time being required to assemble DL messages. Another possible source of delayed responses is pilots' concerns about complying with clearances unless the system is capable of unambiguously identifying the source of a message and of ensuring its integrity. This requirement was identified in the literature and again emphasized by participants in this study, as illustrated by the following quote:

- "I have to feel confident that that message is my message and it means I need to do that. In this [the current] environment, I know the guy's voice, I recognize the guy's voice from hearing it once or twice. ... But if you are just cruising along and at hour 2.5, a message pops up, 'turn left 240', you go 'Why?' and do I have the confidence that that message is my message. ... We have to build the system to have a high degree of confidence, that the message has integrity and in fact has security."

The ability to delay attending and responding to an incoming message until competing task demands allow for it can create problems with respect to the timeliness and relevance of information (Grice, 1975) and with respect to the establishment of mutual commitments to avoid a diffusion of responsibility. Temporal gaps in the communication between two parties may require that once the conversation is picked up again, it may be necessary to first establish what has been and is now being talked about.

Delays can also have detrimental effects on the important coordination of responsibilities between pilots and controllers. For example, there is evidence that controllers take feedback on the successful transmission of a message as evidence of the pilots' intention to comply with its content, although the pilot may not even have looked at the message yet (see Talotta et al., 1990). The omission of establishing mutual agreement about commitments before an action is taken is also seen in the case of pilots who initiate a requested maneuver before dispatching a response to the corresponding ATC clearance (Waller and Lohr, 1989).

In summary, whatever the reason, the existing potential for delays in communication suggests that current Data Link implementations may not be suitable for handling communication in the future ATM environment where a lot of communication can be expected to be time-critical given the expected tactical approach to traffic management. Even for the current ATC system, many researchers and practitioners agree that Data Link should not be used to transmit time-critical immediate action messages. Still, the currently proposed design and operation of the system allows for and encourages such use of the system (Kerns, 1994). As one controller in this study explained:

- "You and I are on a sector. I'm on the R [radar position], you are on the D side [data position]. I need to tie up the radio and you've got access to Data Link. I tell you 'Dump this guy and turn this guy and climb this guy.' And you're just typing. Boom. Boom. Boom. They're gone. Because I am talking to this other guy on the radio."

This new form of sharing responsibilities and communication tasks across a controller team involves a number of risks. In today's air traffic system, only the radar controller will talk to aircraft under his control even when several controllers are working a sector due to high traffic density and/or complexity. With the new proposed procedure, there is an increased risk that a member of the "radar team" can communicate a (erroneous) clearance to an aircraft without providing the radar controller with an opportunity for timely error detection and recovery. The need for new flexible procedures to support inter-controller coordination was identified in a study on the benefits of Data Link (Data Link Benefits Study Team, 1995). To date, however, the issue of additional coordination requirements between the radar controller and the D-side or even between the radar controller and other primary and secondary assistant controllers in high-workload operations has not been resolved.

Another example of a proposed feature of Data Link that may be useful for the current ATC environment but less so for Free Flight operations is a message log for pilots and controllers to allow them to refer back to and review earlier clearances and communications. Free Flight is not going to involve as many, if any routine ground-initiated clearances. Also, Data Link will most likely be used to transmit routine communications while voice communication will be used for non-routine situations and for urgent messages (Billings, 1996; see also comments by controllers in this study). Thus, a critical proportion of air-ground exchange would still not be available for review by the crew or the controller. This may lead to confusion due to gaps in the log because of the inability to recreate the temporal sequence of voice and Data Link messages.

Given the envisioned widely distributed network of decision-makers and actors in future ATM operations, the number of potential communication partners will increase. As a result, there is an increased need to address the issue of priorities and the coordination of transmissions. For the controller who is supposed to interfere only when safety requires him or her to do so, it is of utmost importance to have the highest priority at any time. Some controllers in our study were concerned and asked for clarification on this point:

- "If I'm going to rely on Data Link to give control instructions that need somewhat close to an immediate response, am I going to have first priority of the Data Link or is dispatch going to have first priority if multiple transmissions are being received ? "
- Another controller asked, "Do we have to compete to get in? "

One way of dealing with this message would be to tag messages according to their urgency—an option that has been proposed in the context of current Data Link designs. While it is technologically feasible to introduce such a function and while agreement on the associated procedure may be possible, it is important to keep in mind that this function involves a number of potential problems. First, it will create a new task for the sender and receiver of a message and create an additional step in the creation and screening of a message. Also, in the current voice communication environment, the urgency of a message is often inferred from implicit voice cues (in addition to explicit cues such as the use of the word “immediately”) as confirmed by controllers in a number of surveys (e.g., Sarter and Woods, in preparation):

- “I can tell immediately by the tone of his voice whether this is a ‘do it immediately’.”
- “Today, when I check in on a frequency, within a minute I know what the workload of the controller is. And I know whether I can talk about things, or to just shut up until he’s called and his ears pick up.”

As pointed out earlier, urgent messages may represent the majority of transmissions in the future tactical air traffic environment. As a result, their relative frequency may increase dramatically and with that, the informativeness of the label “urgent” can be questioned.

Also, the urgency of a message in a widely distributed network of decision-makers and actors can not be determined by the sender alone. It is the result of an interaction between the intentions, actions, and limitations of both sender and receiver. Thus, currently proposed schemes may not be suitable for future ATM operations as they suggest that pilots and controllers do not have to attend to messages immediately unless it is urgent when, in fact, every message has to be checked by the receiver to determine urgency based on context.

7.4 The Need for a Context-Dependent and Operator-Controlled Choice of Communication Media.

Participants in our conceptual walkthroughs agreed that the key to successfully handling highly dynamic high-risk situations in the future ATM system will be a high degree of flexibility to allow for the context-dependent selection of communication media and protocols. They pointed out that in a situation such as the transition from Free Flight to a more controlled environment, the choice between Data Link and voice will depend on a variety of factors such as the urgency and length of messages that need to be transmitted, the ease with which messages can be assembled in either medium, and the equipment on board those aircraft that are affected by the transition.

Most likely, Data Link will be the preferred medium in situations where a precanned message can be sent to a number of aircraft or where a new broadcast message can be created very easily using the Data Link system. In contrast, controllers would prefer to use voice communication in case of an extremely urgent message or when numerous different messages need to be sent to a large number of aircraft. Still, even these preferences may change depending on the design and functionality of the Data Link system. Controllers explain that voice communication may no longer be their preferred technique if datablocks are updated automatically for them once a message has been sent and acknowledged. Both groups, pilots and controllers, agree that the choice of the communication medium should be left to the party initiating the communication, and that mixed protocols should be possible. This view does not coincide with current proposals calling for procedures to regulate the choice and combination of communication media. It also contradicts empirical findings which show that after working with mixed protocols, pilots and controllers in several studies (e.g., Hinton and Lohr, 1988; Talotta et al., 1988) felt that switching between media was not desirable because of the difficulty in synchronizing the timing of the two media (Kerns, 1994).

One of the few areas where pilots and controllers would prefer to maintain a high degree of regulation and standardization is in terms of phraseology. Standard phraseology is considered particularly important to avoid misunderstandings in situations that require immediate compliance with a clearance and also to allow controllers to create precanned messages for Data Link communication. For example, in a situation where the controller needs to take a large number of aircraft off their Free Flight status, standard agreed-upon phraseology would eliminate unnecessary requests for clarification and negotiation, and it could also be used to convey information such as the urgency of an action provided both controllers and pilots are well trained on the significance and meaning of standardized phrases.

Negotiations of messages (especially controller instructions in case of time-critical situations) should not be allowed, in the view of most controllers and pilots:

- "I can always get on the phone later and ask for an explanation (for why he was taken off Free Flight). It's not something to get in an argument about at 30,000 ft when you're descending into LA."
- "Once that [a controller clearance for traffic separation] is transmitted, in a form of action, it has to be executed immediately".

7.5 The Need For Practice-Centered Displays For Data Link Communication

Another area of concern that was discussed with pilots and controllers during the focus group meetings is the need for practice-centered feedback and interface design for digital communication. In particular, controllers were worried about new demands in terms of attention allocation across numerous displays and about an

increased need for focal visual attention. Earlier research indicates that an increased head-down time can be expected for pilots who may both want to read the message given that they can no longer listen to and share the information over their headphones. For controllers, there is a potential for an increased head-away time (away from the radar scope) if communication-related information is not integrated with that display. Given the large number of competing attentional demands, controllers would prefer at-a-glance displays that allow for parallel processing of different kinds of information. For example, the case of a transition from Free Flight to a more controlled environment potentially requires message acknowledgments by a large number of affected crews. These acknowledgments can not be handled via voice communication as the controller may have to use this channel for issuing urgent clearances. As long as other effective feedback mechanisms are provided, this does not create concerns among controllers:

- “If I don’t have to listen to it, and his transponder Mode S and Data Link and everything is feeding my radar display to where I don’t have to listen to it, all I have to do is to scan visually; that would make less of an impact. If he starts to turn, it tells me.”

However, controllers are worried about having to track pilots’ acknowledgments by referring to a separate message list. Instead, they suggested to have the color of affected radar targets and their datablocks change once an acknowledgment has been received by the Data Link system. Given that all affected aircraft are likely to be in close spatial proximity, this design would support pattern recognition.

Some currently proposed Data Link designs already involve the integration of Data Link-related communication with the information on the radar scope. Attempts are being made in current designs to provide information on the contents and status of Data Link messages as part of the datablock of the affected aircraft. While this design moves in the direction desired by controllers in our studies, it still involves a number of problems. In particular, no indication is provided to indicate whether a message has actually been received (not only sent) and is currently being reviewed by the crew.

Also, it is not clear that these proposed designs would work well for clearances involving multiple information elements. And finally, the addition of data to the datablock may seem unproblematic when applied to a single airplane. However, if applied to a large number of datablocks, this design will further increase the number of competing focal visual demands on controllers.

More effective ways of providing information on the status and contents of Data Link messages as part of the datablock should be pursued, as they involve the potential for supporting error detection and recovery. For example, when the D-person is sending clearances to aircraft via Data Link, the change in datablock indications may help the radar controller keep track of his/her actions and notice erroneous inputs.

7.6 Concluding Remarks

In summary, communication purposes and demands in future highly flexible ATM operations are likely to differ considerably from those in the current highly standardized and regulated ATC system. Communication will no longer serve the creation of agreed-upon commitments and thus long-term planning and control. Rather, it will be used to exchange information on actions already taken and to resolve time-critical conflict situations. Routine communications are more likely to be initiated by pilots to inform ground-based operators of their actions while conflict solutions will be communicated by controllers.

The design of communication systems and protocols needs to be tailored to these demands and procedures to ensure highly efficient communication in the interest of coordination between airborne and ground-based operators. This research is a first step towards better understanding those new demands and, working in cooperation with practitioners, to explore the feasibility and effectiveness of various possible approaches to the exchange of information and the establishment of commitments in the context of Free Flight.

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HUMAN-CENTERED TECHNOLOGIES AND PROCEDURES FOR FUTURE AIR TRAFFIC MANAGEMENT

8. ADVANCED AIR TRANSPORTATION TECHNOLOGIES: PROBLEM DEFINITION AND EXPLORATION OF A SOLUTION SPACE

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8.1 Statement of the fundamental problem and goal

The fundamental problem motivating the search for new technologies to support a more capable air traffic management system is the inflexibility of today's increasingly crowded air traffic management system, which is inefficient and costly for users of the airspace. The goal of the AATT project is to assist in the design of an air traffic management system that will increase the ability of all suitably equipped aircraft to fly when and where they wish under all flight conditions, with at least as high a level of safety as is now available in the current air traffic management system.

8.2 Dimensions of the problem space

Drawing on the data collected in these studies, we have conceptualized this problem in terms of several physical and operational parameters, and a number of variables that relate to the processes necessary to accomplish the objectives of the system. Considered as a whole, these parameters and variables may be thought of as defining a problem space, within which a solution space may be hypothesized.

8.2.1 Physical Parameters

The physical parameters of primary importance include (but may not be limited to):

- The dimensions and characteristics of the usable airspace within which operations are to be conducted;
- The number, type and position of airports suitable for those operations;

- The aerodynamic characteristics of the vehicles operating in that airspace and to and from those airports;
- The precision within which the airspace itself, and vehicle positions and states within that airspace, can be defined on a dynamic or real-time basis;
- The availability of position and state sensors, and their precision under both nominal and worst-case conditions;
- The availability and capacity of real-time communications media to permit information transfer within the system and among its participants and stakeholders.

8.2.2 Operational Parameters

The operational parameters of primary importance include:

- The range of operational capabilities required by system users (general aviation, air carriers, the armed forces and other users must be considered);
- The constraints under which system users wish to or must operate, and the regulatory infrastructure that controls and constrains their operations;
- The ability of system users to equip their aircraft with necessary technologies;
- The range of capabilities of the operators of aircraft, and of the ATM infrastructure.

8.2.3 Major Variables

The variables of primary importance in such a system relate mostly to information relating to, or generated by, the system. They include:

- The processes, policies and procedures under which the system will be operated;
- The agreed-on methods by which the system is to be controlled and managed;
- The information that is made available by operators, the ATM system and others;
- The degree to which that information is accessible to other operators and users;
- The methods by which information is transferred;
- The loci of control of the system under normal and contingency conditions;
- The spans of control and management of the various system participants (human and machine).

The aviation system is information-bound. It is able to function only to the extent that various operators have access to information concerning both their own operation and the operations of others, and information concerning the environment in which they are operating and will operate in the near future. (This is sometimes referred to as "situation awareness".) The management of the system is constrained by the manager's ability to manage information that describes the environment, objects being moved within it, and the intentions of the participants.

8.3 Bounding the dimensions of the problem

Each of these parameters and variables has limits that are relevant to the goal and to a definition of a problem space that is bounded enough to be tractable. An attempt is made to do this here.

8.3.1 Physical parameters

We assume that the physical dimensions and characteristics of the airspace are to remain as at present, with certain specific exceptions:

- Military special-use airspace will be made available for civil operations at any times when it is not in active use. Its physical dimensions may also be dynamic;
- Terminal (departure and arrival) airspace will be controlled only as required; its spatial dimensions will typically vary dynamically based on need.

Airspace parameters must therefore be thought of in both spatial and temporal terms.

Airports, with a few exceptions, will remain as at present. A small number of additional runways may become available, but the principal difference from today's operations is that runways will be more heavily used. There will be continuing and increasing pressure to minimize runway occupancy times. Aircraft surface movements at high-density airports may be controlled automatically to a limited extent to permit more operations under extremely restricted visibility conditions.

While the types of aircraft in the system will not differ appreciably from those in use today, a decreasing number (except in the near term) will be "first-generation" machines. An increasing majority of aircraft will have relatively high power-to-weight ratios under normal operating circumstances. They will therefore be somewhat more agile. Most transport and many business aircraft will have at least a flight management system with vertical navigation capability. Nearly all will have collision avoidance systems of some kind, and a large number will have data link capability (mode S or other).

Airspace physical dimensions can be very precisely defined with present technology. The challenge in this area will be the pressure to delimit or restrict airspace only

when operational necessity dictates (temporal dimensions). Dynamic airspace reservation implies the existence of means whereby information concerning dynamic airspace dimensions and rules for its use can be made known instantly to those who may wish to use it, or may need to avoid it. We assume that aircraft positions, states, and instantaneous velocity vectors can be defined precisely enough, using presently-available technology, so that data concerning them can be considered "true" and current. Constraints are likely to be due to problems in information management rather than problems in generating the information.

If the above assumptions are correct, the physical parameters of the future system can be fairly precisely defined except to the extent that they become dynamic. The issue of critical importance becomes the ability to transfer information, which is or will be available, among the system operators who may have need for it under any operating circumstances. As noted, the present system is information-bound. A more dynamic system will be even more dependent on our ability to manage information, and there will be more, and more dynamic, information to manage.

8.3.2 Operational Parameters

These parameters must be defined by consensus among system participants. Once defined, they will become, in effect, system constants. We believe that the range of operational capabilities that the system can support will not change greatly during the period of definition of the future system, though there will be additional requirements placed on specific parts of the system (primarily low-altitude sectors).

Air carriers desire markedly increased system capability to accommodate flexible operations within which tactical changes in objectives can be dealt with in real time. They want, at least for their aircraft, the ability to utilize "best" routings without hindrance (and "best" may be defined differently by various system participants, or even by the same participants operating under differing constraints imposed by weather, equipment availability or passenger demand). Operators may be expected to echo the desire for flexible operations whose trajectories can be defined in real time to accommodate changing circumstances.

Air carriers, operating under FAR Part 121, will be willing to accept the constraints imposed by the FAA in the interests of maintaining the highest level of safety. Other operators, however, are not bound by these regulations. As they become more sophisticated, they may be expected to press for the ability to conduct operations permitted by FAR Part 91 under all circumstances. The implications for the ATM system of this have not been considered in depth.

For some years to come, there will be considerable differences among operators in the sophistication of their avionics suites. Initial plans suggest that the future ATM system must accommodate the entire spectrum of aircraft, but we believe there may be considerable pressure on operators to invest in advanced avionics in order to be able to realize maximum system capabilities.

There remains the important question of operator capabilities. ICAO has set forth minimum standards for aircrew, and nearly all nations adhere to these standards or to similar national regulations. The facts are, however, that while minimum standards may be met by all, there remain substantial differences among nations and regions as to the average capabilities of their commercial pilots and their air traffic controllers. There are still large regions in which air traffic control, and air navigation equipment, are not fully reliable, and some nations whose pilots do not operate to what we would consider optimal standards. We have listed this as a parameter because these capabilities will improve, at best, only very slowly over time. The globalization of air transport means, among other things, that operators from these nations operate over our land mass, and our operators operate over theirs. The future system must be sufficiently tolerant of differences in human and equipment capabilities to permit operations, wherever they may occur, at a uniformly high level of safety.

8.3.3 System variables

In addition to these parameters, a host of variables must be taken into account in planning for a future system. These variables, however, can be controlled to a greater extent than the parameters considered above. As noted earlier, the most important ones relate in some way to the handling of information in the system, because it is information that ties this very complex, dynamic, highly-distributed system together. The system has many loci of control: air traffic control and air traffic management centers, airline operations centers, and aircraft. All must operate cooperatively, in agreed-upon ways, if the system is to be successful.

These agreements, however reached and codified, constitute the body of philosophy, policies, procedures and practices (Degani & Wiener, 1995) that govern operations in the aviation system. This fact implicitly recognizes that the goal cannot be met in an unconstrained system; the solution space will be more constrained than the problem space. It also means that the ground and flight subsystems must be integrated by agreements as to the methods by which air commerce will be conducted.

These methods, or procedures, will indicate what aircraft trajectories are, or are not, permissible under the range of circumstances that may obtain in the system. They may differ as a function of the technologies available in a particular region; they should (but may not) differ as a function of the capabilities of the various human and machine participants. They must obviously be known to all participants in a given area, which implies that *ad hoc* rules and agreements are not desirable.

The procedures, and their implementation, rest upon a body of philosophy and policies adhered to by controlling bodies (usually governments) and operators. For this reason, the philosophy and policies must also be known to all system participants. This has not been the case in the past, and it may not be the case in the future. Many "private agendas" govern operator methods, and some of them involve competitive considerations, at least in the United States and increasingly,

elsewhere as air transport becomes more competitive world-wide. The extent to which proprietary considerations threaten system integrity is not known, but enough is known to state with confidence that the overarching philosophy and policies must form boundaries outside which operators cannot stray.

If such boundaries are to exist, and if a common operating philosophy is to govern all system participants, there must clearly be a body which can act as a repository for the agreements, a "referee" when participants disagree about operating methods, and an enforcement mechanism when agreed-upon operating practices are transgressed. This body is also a logical repository for dynamic information concerning the system, though it does not represent the only possible solution for the information management requirements of the system. Only if this body has the ability to compel participants to conduct operations within its rules, however, and to provide information necessary to the conduct of air commerce, will the enterprise be successful; for that reason, it can be argued that it should be a governmental body.

There are two major classes of direct participants in the present system: users (in airlines, this includes flight crews, dispatchers and airline operations centers that direct them, and other management and support staff) and providers (air traffic controllers and managers). At this time, each class of participant has well-defined responsibilities, and usually well-defined authority to meet its responsibilities. Flight crews and dispatchers are responsible for the safe conduct of their own individual flights and fleets; air traffic controllers and managers are responsible for the safe conduct of air traffic. Each class of human operators is assisted by a variety of automated tools, though controllers presently have less advanced automation technology at their disposal than do the other operators in the system.

It can be argued that air traffic control and maintenance of separation between aircraft is the most difficult task in air commerce, and that this task will become more difficult as demand for air transportation increases. This reasoning has led system overseers to propose that advanced automation for the performance of this task should be the highest priority of system designers. Indeed, it appears that a major part of air traffic management system redesign is devoted to this task, though considerable effort is also being applied to upgrading aviation communications systems as well.

Our conceptualization of the problem space, above, suggests that fully adequate information management capability may be at least as important as tools to assist controllers in maintaining separation. It can even be argued, as an extreme position, that if fully adequate information concerning the system were available to all operators on a real-time basis, losses of separation among aircraft would be much less likely to occur, since operators could plan and conduct their operations with foreknowledge of possible conflicts between themselves and others.

The availability of data concerning system parameters and variables is not enough, in and of itself, to permit safe system operation. These data must be properly

transformed, integrated and represented to the various system operators in such a way that they tell operators what they need to know, when they need to know it, in order to make uniformly intelligent decisions about their conduct of operations. The present system's information management infrastructure is a patchwork of equipment and methods developed over many years. It is less than adequate to meet operator needs now, and it will become grossly inadequate in the near future. Though much research and development is ongoing, especially with regard to high-bandwidth digital communications capability (digital data link, see report no. 7), more research is required to delineate more precisely the information requirements among system participants; the lack of such information is a major part of the problem.

One final note with regard to variables: Automation can limit the authority and span of control of human operators in the system. It already does so in advanced aircraft, and it may do so to air traffic controllers as the ATC system becomes more automated. We believe that responsibility for system safety and authority to operate the system must reside in the same locus of control. If humans are to remain responsible, they must have the authority to override their automated tools. This becomes increasingly difficult as automation becomes more autonomous and authoritarian. The limits of authority of new automation must be clearly spelled out at the conceptualization stage, to insure that fundamental system principles and practices can be maintained under all circumstances.

8.4 The Range of Solution Options

The next-generation aviation system will not be *fully* automated, either on the ground or in the air. We do not believe that the capability exists at this time, with today's technology, to build either fully autonomous aircraft or a fully automated air traffic management system. We also believe that social and political constraints would make the use of such systems unacceptable to customers and managers alike even if they could be designed, built and validated. For that reason, we suggest that the next-generation system must continue to be a *cooperative* human-machine system, in which human operators will continue to be the ultimate defense against system failure.

This being the case, we suggest that the solution space for the future system must be limited to solutions in which human system participants remain in a position of primacy over machines. Much more automation will be required to meet future challenges, but that automation should be designed to assist humans in doing their jobs within the system, rather than supplanting them. This implies that the automation must be human- or user-centered; that automation technology must be designed as a set of tools that humans can use to accomplish tasks necessary to safe system operations.

Further constraints will govern the solution space for a future aviation system. They are presented as discussed in previous sections.

8.4.1 The physical environment

The physical and temporal characteristics of the usable airspace will continue to be governed by convective weather phenomena, and to a lesser extent by precipitation activity, both of which vary dynamically. Aircraft will continue to avoid, rather than deal with, convective activity; snow and sleet will continue to be a major problem at and in the vicinity of airports. The future system will continue to be plagued by certain types of weather, though new technology can help to deal with problems of low visibility due to fog.

Because of this, the future system must be sufficiently flexible to accommodate and deal with large-scale disruptions of air movements when these phenomena are active. Its present inability to do so in a way that meets airline needs will be a source of continuing pressure from these operators, and more effective contingency management should be a major sub-goal in system redesign. This issue needs more research than it has received.

While today's sensor systems can locate aircraft with high precision, the ability to transfer and represent these data in real time may continue to pose a serious problem. Enormous quantities of electromagnetic spectrum resources will be required to provide all system participants in real time with all the information they need to conduct operations intelligently. This has the potential to become a major system bottleneck, for aviation communications will increasingly be forced to compete with other communications in an increasingly information-driven society. We have already seen problems due to this competition.

8.4.2 The operational environment

While some have suggested that the future operational environment can become simpler to understand and less constrained by strategic considerations if a free flight approach is adopted, we believe that this suggestion is simplistic. A lessening of dependence on strategic air traffic management will require that operational decisions be made more rapidly when problems arise, and will also require that solutions be based on less information than is presently incorporated into such decisions, because intent information may not always be available and there may not be time to seek it out.

We believe, and the data reported in this volume strongly support this belief, that the aviation system must continue to have access to information concerning the intentions of all system participants, because situation awareness requires the ability to predict near-term future system states (see reports nos. 3 and 5 in this volume). This is true whether humans, or computers, are in control. We therefore believe that the future system must continue to rely on intent information, and that means must be found to improve the quality and ease of transfer of this information among participants.

We think it likely that if there is sufficient demand for advanced tools to permit full participation in a future system, avionics manufacturers will produce these tools and will make them affordable to those who wish to purchase them. This has already occurred with respect to satellite-based navigation systems, just as it earlier occurred with respect to advanced navigation and communications systems for general aviation; even before GPS became available, nearly 50% of general aviation aircraft had some area navigation capability.

The capabilities of aircraft operators is a more difficult issue. Aircraft operators in the United States vary greatly in their abilities and proficiency, as well as in the tools they possess to aid them in functioning within the system. We believe this disparity among operators will continue. We are not sure that the solution space for a future aviation system can be enlarged enough to meet the needs of the present population of pilots wishing to utilize it, but political realities dictate that every effort should be made to keep the space as wide as possible in deference to this population. Nonetheless, significant compromises may be required to make the full capabilities of the system available to all who wish to use them.

The problem with regard to other areas of the world is even more difficult, and perhaps insoluble in the near term. This dictates that aircraft capable of operations to and from those areas must be prepared to operate, under all conditions, without many of the capabilities that their operators are used to having in flying within the United States or other technologically advanced areas. International transport pilots now become used to conducting much of their own air traffic surveillance, using voice transmissions, TCAS and their own eyes, because they know that air traffic control in those areas may be unreliable. The future system must be designed in such a way that it does not lessen the ability of pilots to take on these additional responsibilities where they are required. Growing dependence on data link as a means of discrete communication between aircraft and the ground infrastructure could rob pilots of information they now need in these areas, as an example, although it could appreciably ease some of the present problems due to disparities in English language capability (see report no. 7 in this volume).

8.4.3 System variables

As we believe that information management and transfer are the central problems facing us in working toward a future aviation system, we also believe that the dimensions of the solution space will ultimately be constrained by our ability to conceptualize the future system in terms that permit solutions for this central set of problems.

It is our view that the future system's effectiveness will rest primarily upon the effectiveness of its information management. This view encompasses all facets of information generation and handling. This is an area in which advanced technology can be of the greatest help to the humans who must manage and operate the system. It is vital, however, that the conceptual architecture of candidate systems be worked out in advance of system design, to guide the information

management requirements and the design of technologies necessary to aid information flow and representation in the various parts of the system.

The system architecture must be guided by the overall system philosophy, which will also motivate the assignment and distribution of operating tasks to be performed; these, in turn, will govern the information necessary for operators, and the forms that information should take. These decisions, in turn, should enable decisions to be made about the types of automation necessary to assist human operators and managers of the system.

In other words, it is our belief that several major efforts need to precede detailed system design. We believe that technology to assist humans in managing any of several candidate systems is technically feasible, whereas technology to manage a future system autonomously is not. We believe that a system in which human-centered automation assists humans in system management and operation is likely to provide the flexibility that will be required, while a system that depends more heavily on automation itself for its operation is likely to be brittle and inflexible.

8.5 Integration and Coupling in a Future System

We have indicated above that we believe that future system integration should be accomplished by means of a philosophy, policies and procedural rules, understood and agreed to by all system participants. Such a system will need to be flexible as well as capable, in recognition that there will inevitably be operational conditions not predicted nor provided for by system designers. In a system with the amount of uncontrollable variability that exists in the aviation system, this is a conservative and prudent approach.

We are concerned about the amount of coupling, or interdependence among system components, that would be required in a fully-automated system. In past heavily-automated systems, this coupling has increased system brittleness at the margins of the system's operating envelope. It has led to such systems becoming more opaque to human operators, and has therefore increased the likelihood that human system operators or managers will be surprised by system behavior. We therefore believe that this enormous system redesign task should incorporate conservative design approaches, that the future system should be as evolutionary as possible, and that as much use as possible should be made of the enormous amount of human expertise and capability now existing. It is these human experts who will be relied upon to operate, supervise and manage the future system. Their collective capabilities, properly enhanced by new technology, represent the greatest asset we have, and should be the basis upon which the future system is founded.

Reference

Degani, A., & Wiener, E. L. (1991, April). *Philosophy, policies and procedures: The three P's of flight-deck operations*. Paper presented at the sixth International Symposium on Aviation Psychology. Columbus, OH.

